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SAMUEL CALVIN

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Samuel Calvin, who died at Iowa City, Iowa, April 17, 1911, was born in Wigtonshire, Scotland, February 2, 1840. He passed the first eleven years of his life in the little town of Wigton, living the simple, hardy life common in Scotch families of moderate means. As a boy, after school hours, he often paused at the edge of the cliff to look down upon Wigton Bay in which lay ships and schooners from all parts of the world. At that period trade between America and the various little ports on Solway Firth was active, and the longing for travel, common to all boys, was greatly stimulated in young Calvin by the sight of the vessels that came and went. Among his school companions was James Wilson, now Secretary of Agriculture, and a friendship was there formed that continued through life. The Calvin and Wilson families both emigrated to the United States in 1851, the Calvins going direct to Iowa and the Wilsons following after a short sojourn in Connecticut. Thomas Calvin, the father of Samuel Calvin, took up land south of Manchester, Iowa. At that time neighbors were few and far between in eastern Iowa. The first residents came from Indiana and, being accustomed to a wooded country, feared to venture upon the open prairie. They accordingly settled near the streams on what proved to be the poorer land. The Calvins and their associates, evidently thinking that having ventured so much in coming from Scotland they might as well venture more and save themselves

the work of clearing off timber, chose prairie land. It thus happened that from early boyhood Samuel Calvin was familiar with the great granite bowlders that mark the fertile prairies covered by the Iowan drift. Between farm work, school, and the usual country sports, his time was fully occupied until about 1861, when he entered Lenox College, at Hopkinton, near by. Lenox College, was, and is, an excellent example of the small denominational colleges that the pioneers of the Middle West founded so prolifically and supported with so much sacrifice. Without the equipment of a present-day university, or a staff of world-famous professors, it was still an excellent place for a young man desirous of getting at the fundamentals of the simple college curriculum of a half-century ago. Here Calvin remained and studied until near the close of the great Civil War, when, in company with most of the instructors and students who had not already gone to the front, he enlisted in 1864 in one of the Iowa regiments. Fortunately the war was nearly over. His military service was therefore neither long nor was it distinguished, in the sense of taking him into great battles. For the most part it was a period of dull routine, of guard duty and of marching, of occasional small skirmishes with the enemy, and a continual private skirmish for acceptable food and some comfort. He learned the rudiments of a soldier's life and the routine of camping—the latter much the more valuable to him.

At the close of the war, Calvin, with many others no longer young, went back to college to finish his studies. The college, however, had been practically wrecked. The call for men had taken both instructors and students, and while the buildings were still there, the life of the institution had been nearly broken up. After the ensuing reorganization Calvin found himself in the ranks of the instructors rather than among the students, and the interrupted college course was only completed as a result of much hard private study.

At Lenox College, among other members of the new faculty, was Thomas H. Macbride, a graduate of Monmouth College, and a man who had had the advantage, then unusual for teachers in small western colleges, of study at the University of Bonn. Macbride's interests centered in botany, and Calvin, while broadly

concerned with the whole of natural history, was already beginning to specialize in paleontology and geology. The two men became intimate friends and close companions. Together they explored the neighborhood and later, in the long vacations, the more distant parts of Iowa. With team, covered wagon, and simple camp outfit, trips were made as far west as the Missouri River, and collections of various sorts were brought back to enrich museum and classroom instruction. In the course of this work Calvin came into contact with C. A. White, at first state geologist and later professor in the State University at Iowa City. When White went East Calvin succeeded him at the university, and when the Iowa Geological Survey was re-established in 1892, he also followed him in the position of state geologist. The change to Iowa City, which took place in 1874, was an agreeable one, since the university, having larger resources, offered a larger opportunity for work; and for work Calvin always was greedy. The State University of Iowa in 1874 was not a large institution and the professors found plenty to do. Calvin occupied what has been aptly described as the "settee rather than chair" of natural history, and, as he once whimsically phrased it, he was ever after "shedding professorships." As rapidly as funds would permit he divided the work and called other men to him. Among the first was Macbride, then Nutting, and others in succession until in the closing years of his work it was not only possible for him to confine his work to geology, but to have the aid of an able corps of assistants in that. His work in the other sciences, however, was more than time-serving. His interest in animal morphology was especially keen, and in organizing and conducting zoölogical explorations he did work of real value. The results of the Bahama expedition, which brought back such unheard-of wealth of specimens of living crinoids, were due in no small part to him.

As a geologist Calvin's name and fame are principally bound up with that of the Iowa Geological Survey, which, except for a brief interim, he directed from the day of its organization, in 1892, to the day of his death. As a former member of the staff of this Survey I may be over-partial, but it is none the less my conviction that, considering time, place, and means, the Iowa Survey is and has

been one of the best-conducted institutions of its kind in America. It serves the people and the state of Iowa well, meeting their peculiar needs. In other states different methods are necessary, as they will become in time in Iowa.

The Iowa Survey owes much to Calvin. It also owes a not-to-be-forgotten debt to Charles R. Keyes, the principal assistant at the time the Survey was organized and through the period when plans were being formulated. In brief the Survey has served two main purposes: (1) It has furnished handbooks, consisting of maps and reports on the geology of the individual counties, written in simple language adapted to the understanding of students and intelligent laymen; (2) scientific and technical reports have been issued as occasion offered, covering all phases of the natural history of the state and the economic development of its resources. According to the report for the year ending December 31, 1909, all but nine counties had been surveyed and reports prepared and issued. More detailed surveys, based on topographic maps made in co-operation with the United States Geological Survey, had already been begun in areas of especial economic importance, and, as conditions permit, this system of more refined mapping will doubtless be extended over the state. In the meantime the county reports serve extremely useful purposes and afford a sure basis for broad general studies. The special reports on scientific and economic subjects have been numerous and valuable, as is attested by the list of publications of the Survey. The water, the coal, clay, stone, lead, zinc, gypsum, and minor mineral resources have all been studied by specialists, and information essential to their economical development set forth. The mineral industry has responded to the stimulus and the total value of the mineral output of the state is now many times what it was when the Survey was organized. Iowa is primarily an agricultural state and its mineral resources are relatively small; the educational phases of the Survey work have therefore always, and properly, been emphasized. On the narrow material basis, however, the Survey has made good return for the support of the state and it is deservedly popular. As an administrator, therefore, Calvin's work shows him to have been successful.

In scientific research, Calvin's personal interest lay mainly in paleontology and, in later years, in the study of the Pleistocene deposits. Aside from contributions to the paleontology of the Paleozoic invertebrates, Calvin will probably be best remembered for the discovery of the fauna of fish remains in the Devonian beds near Iowa City, and for his studies of the vertebrate remains of the Aftonian deposits. The fish remains have been investigated by C. R. Eastman, who found in them much of interest. The Aftonian bones are important because they permit fixing the age of a widely scattered series of puzzling deposits. In his last published administrative report[1] Calvin speaks of them as follows:

> This remarkable interglacial fauna is not altogether new to science. The individual species, and to some extent the fauna as a whole, have for some time been known to students of paleontology. It has also been known that some of the species were at one or more times inhabitants of Iowa. But, so far as concerns Iowa, it was not known that the few discovered forms, which heretofore have been represented by isolated finds, were contemporaneous; and outside of Iowa, in territory ranging from Texas to western Nebraska, the exact age of the beds in which the remains of this assemblage of extinct mammals were found was not definitely fixed. The fauna as a whole is markedly different from that familiar to the pioneer settlers of this State, very different from that known to the pioneers in any part of America. True horses were represented by at least two species, both quite distinct from our domestic species; there were three species of elephant, one of imperial size, and there were two mastodons, making in all five great proboscidians; there was at least one species of camel, an extinct bison, a gigantic stag, and two ponderous, awkward, clumsy ground sloths. The smallest of the three elephants seems to be identical with the hairy elephant or northern mammoth of Europe and Asia; it furnishes to this unique fauna a distinctly boreal element. The two great sloths, on the other hand, contribute an element distinctly South American. As found in Iowa, the age of the fauna is definite and clear. The beds in which the remains occur belong to the Aftonian stage; these animals lived, and the beds in which their remains were buried were laid down, in an interval of comparatively mild climate between the first and second stages of Pleistocene glaciation.

The quotation illustrates at once Calvin's broad scientific interest and the singular clearness of his writings, which makes it a pleasure to readers and a fit model for beginners.

Calvin's active interest in the Pleistocene deposits dates from

[1] *Iowa Geol. Surv.*, XX, xxii.

1896. In the spring of that year he undertook to put into shape long-accumulated notes on Johnson, the county in which Iowa City is situated. It chances that two lobes of Iowan drift reach across the northern border of this county. South of these lobes are the loess hills characteristic of much of the Iowan border and, in turn, the broad loess-Kansan plains. At that time the southern boundary of the Iowan had not been traced. From the known presence of two drifts at Afton and elsewhere in southern Iowa, it had been inferred that the Iowan boundary was much farther south than now appears true. The battle for two ice-sheets has been but too recently won to encourage belief in many. Calvin, however, intimately familiar with the typical Iowan drift plane of Buchanan and Delaware counties, recognized at once that the phenomena of southern Johnson County required a new interpretation, and shortly thereafter hit upon the clue. The rest of the staff, inspired by his enthusiasm, started out like crusaders to overturn and rebuild the Pleistocene column. The field was particularly favorable since in Iowa the different drift sheets are mainly deployed rather than superimposed, and since, also, nearly the whole sequence is represented. With the kindly counsel of T. C. Chamberlin, with friendly visits from R. D. Salisbury, J. E. Todd, Albrecht Penck, Frank Leverett, and others, the work went rapidly. There were many field conferences, and the winter meetings of the Iowa Academy of Science became notable for the discussion of current Pleistocene problems. Naturally there were differences of opinion and later work has shown the need of some revision of first-stated conclusions. Out of it all, however, has come the recognition of the independence of the pre-Kansan, the thorough establishment of the Aftonian, and the concept of the Iowan ice sheet. As to the latter, especially, there has been, and still is, much difference of opinion. The Iowan drift is so peculiar, it is so local, and the phenomena are so puzzling, that some find themselves unable to accept the evidence of its existence. It is not my purpose to review the proofs. That has already been done most excellently by Calvin himself. It is sufficient to repeat here a remark made by him at the close of the first field season devoted to this study: "The Iowan ice sheet did so many queer things that

we will never blame anyone not familiar with it in the field for denying its existence; but, whatever the explanation, there is a consistent and co-ordinate set of phenomena that demands explanation, and that is best interpreted by the hypothesis of a separate Iowan ice sheet."

Aside from his work at the university and on the Iowa Survey Calvin did his full share in the general work of his chosen profession. While he was not especially interested in economic geology, his advice was sought and valued by a number of Western mining companies; he was a member of the first Conservation Conference at the White House; he served on the National Advisory Board on Fuels and Structural Materials; he was an active member and officer of numerous professional societies, including the Geological Society of America, of which he was president in 1908; he was one of the founders of the *American Geologist*, and of the Association of State Geologists; and in many other positions he made his influence felt. He was a charming writer, a popular lecturer, and a most inspiring teacher. His personal influence was strong and deep, and the thousands of students who came into contact with him are today better men and women because he lived. He left a stainless record as a man and citizen, and an inspiring example to young men of the profession.

THE EVOLUTION OF LIMESTONE AND DOLOMITE. II (*Concluded*)

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PART II. CALCIUM AND MAGNESIUM IN THE PRODUCTS OF METAMORPHISM

The products of metamorphism of the rocks may be classed as solids and solutes, or residuals and losses. Residuals, the materials which remain *in situ* after a rock has suffered chemical change; losses, the materials which are dissolved, transported in solution, and redeposited elsewhere. A study of the fate of calcium and magnesium in rocks subjected to metamorphism shows that there is nearly always a marked tendency for a greater percentage loss of calcium than of magnesium. Magnesium tends to remain with the residuals to a greater degree than calcium. It will be shown that in the movement and redisposition of the residuals and losses of rock alteration, and in the reworking of these products by the same processes, again and again throughout geologic time, lies the history of a progressive enrichment of the lands in calcium and their progressive depletion in magnesium. The evidence for the selective splitting off of calcium from the parent rocks in response to metamorphic processes and the accumulation of magnesium in the residuals follows.

Materials lost by the weathering of acid igneous rocks.—The weathering[1] of acid igneous rocks results in the loss of lime, magnesia, soda, potassa, and silica. The percentage loss of the various constituents approximately follows the descending order in which they are named. For purposes of comparison alumina may be regarded as constant. The ratio of calcium to magnesium lost in the weathering of an acid igneous rock can only be given in terms of tendencies. In Table V the figures for the ratio of cal-

[1] Edward Steidtmann, "A Graphic Comparison of the Alteration of Rocks by Weathering with Their Alteration by Hot Solutions," *Economic Geology*, III, 381–409.

cium to magnesium lost are based on the assumption that alumina has remained constant. The percentage loss of calcium averages higher than that of magnesium, a tendency generally characteristic of metamorphic processes.

TABLE V

WEATHERING OF ACID IGNEOUS ROCKS

ROCK	Ca/Mg FRESH ROCK	Ca/Mg MATERIALS LOST	PERCENTAGE LOSS		SOURCE
			Ca	Mg	
1 Granite.....	2.8	3.33	3.1	31	Watson, *Granites of Georgia*, 318
2 Granite.....	4.9	7.6	98	64	*Ibid.*, 315
3 Granite.....	2.3	5.2	88	41	*Ibid.*, 321
4 Granite.....	6.9	5	59	82	*Ibid.*, 320
5 Granite.....	3.4	4.6	43	32	*Ibid.*, 309
6 Granite.....	5	2.3	27	59	*Ibid.*, 312
7 Granite.....	5	5.2	84	83	*Ibid.*, 312
8 Granite	3.8	3	74	96	*Ibid.*, 327
9 Granite.....	3.9	4.3	78	70	*Ibid.*, 327
10 Granite.....	2.1	2.58	77	65	*Ibid.*, 325
11 Granite.....	3.3	4.8	80	54	Average Georgia
12 Granite.....	1.3	no magnesium lost	23	0	Merrill, *Rocks and Rock Weathering* (Dist. of Columbia), 207
13 Granite.....	1.3	no magnesium lost	21	0	*Ibid.*
14 Phonolite.....	3.3	12	17	5	*Ibid.* (Bohemia), 198
15 Andesite.....	3.4	9.5	77	28	*Ibid.* (Grenada), 208
16 Syenite.....	1.9	1.7	67	78	Clarke, *U.S.G.S. Bull. 330*, 412
17 Gneiss.....	4.2	....	100	76	*Ibid.*
Average.....	3.45	+4.12	59.7	50	

Materials lost by the weathering of basic igneous rocks.—In the weathering of basic igneous rocks, the percentage losses of calcium and magnesium average about even, in Table VI. The ratio of calcium to magnesium lost varies between wide margins, from one to infinity. The materials selected for analyses may have unequaled value in the problem.

Materials lost by the weathering of an average igneous rock.—The ratio of calcium to magnesium in an average igneous rock (Clarke) is about 1.37. The ratio of calcium to magnesium lost by its weathering, calculated on the basis of average calcium and magnesium decrements, is about 1.85.

TABLE VI

WEATHERING OF BASIC IGNEOUS ROCKS

ROCK	Ca/Mg FRESH ROCK	Ca/Mg MATERIALS LOST	PERCENTAGE LOSS		SOURCE
			Ca	Mg	
1 Diabase	2.2	4.1	25	9.5	Merrill, *Rocks and Rock Weathering* (Medford, Mass.), 218
2 Diabase	1.3	1.57	83	61	*Ibid.* (Spanish Guiana), 222
3 Basalt	1.0	.51	47	96	*Ibid.* (Crouzet, France), 223
4 Basalt	1.2	1.4	84	74	*Ibid.* (Kammer Bull.), 222
5 Diabase	.6	.6	98.7	98.2	Merrill, *Am. Geol.*, XXII, 93
6 Diabase	.64	.6	98.6	98.8	*Ibid.*, 95
7 Diorite	1.84	1.85	97.3	97.17	Merrill, *Rocks and Rock Weathering*, 225
8 Augite diorite	1.07	3.13	59	76	Morozewicz, *Zeit. Kryst. Min.*, CXXXIX, 612
9 Diabase	1.08	2.13	84	42	P. Holland and Dickinson, *Proc. Liverpool Geol. Soc.*, VII, 108
10 Boulder	.10	infinity	17.5	∞	*Helen Mine, Michipicoten* (unpub. monograph)
11 Gabbro	2.92	1.25	8.9	6	*Gabbro, Allen Junction, Minn.* (unpub. monograph)
12 Diabase	1.25	1.35	92	82	*Dike, Penokee-Gogebic* (unpub. monograph)
Average	1.27	1.62	66.3	61.5	

TABLE VII

WEATHERING OF LIMESTONE

Rock	Ca/Mg Fresh Rock	Ca/Mg Altered Rock	Source
Carboniferous limestone	148	14.9	*Ann. Geol. Rept. Arkansas* (1890), 179
Average of three analyses	1.4	.23	*Bull. 7, Va. Geol. Surv.*, 97
Knox	1.6	.01	Russell, *Bull. 52, U.S.G.S.*, 25
Galena	1.5	1.2	*Bull. 14, Wis. Geol. Surv.*, 15–16
Galena	1.5	.66	*Ibid.*
Galena	1.5	.64	*Ibid.*
Trias, France	17.2	2.38	Hilterman, *Die Verwitterungs-Produkte von Gesteinen der Trias Formation*, Frankens. *Inaugural Dissertation*, Erlangen, 1889
Plattenkalk	66.0	1.82	F. W. Pfaff, "Ueber Dolomit und seine Erstellung," *Neues Jahrb.*, XXIII, 538
Krebscheeren Kalk	61.0	1.67	*Ibid.*, 539
Average	26.5	2.61	

Materials lost by the weathering of limestones.—In the present stage of earth evolution, the principal contribution of calcium and magnesium from the weathering of the sediments probably comes from limestones. A compilation of the calcium magnesium ratio of several fresh and weathered limestones seems to indicate that the percentage loss of calcium is somewhat higher than that of magnesium and that the amount of calcium given off by the weathering of limestone greatly exceeds magnesium (Table VII).

Résumé of weathering.—It follows from the facts stated that the weathering of igneous rocks and sediments results in the loss of more calcium than magnesium and that in general the percentage loss of calcium is greater than that of magnesium.

Materials lost by dynamic metamorphism.—The dynamic metamorphism of sediments as well as igneous rocks seems to bring about certain definite chemical changes. It is difficult, however, to measure these changes since it is uncertain whether any of the elements are stable in any given case. All that can be done in the problem of determining the relative stability of lime and magnesium under dynamic condition is to compare the magnesium and calcium ratios in the unaltered materials with the calcium magnesium ratios in their metamorphosed equivalents, as shown by Table IX. Secondly, to compare the importance of calcium and magnesium in the minerals of the unaltered and metamorphosed rocks. Table IX appears to indicate that the ratios of calcium to magnesium are lower in the metamorphosed phases than in the unaltered; that is, the percentage of lime lost by dynamic metamorphism appears to be higher than that of magnesium. Concordant with this apparent chemical change is the fact that the minerals which are developed under conditions of dynamic metamorphism are predominantly magnesium and potassium bearing, rather than calcium bearing, such as the micas, chlorites, and amphiboles of Table VIII. It appears that magnesium is better adapted to dynamic condition than calcium. A selective removal of calcium from the zone of anamorphism to the zone of katamorphism and ultimately to the ocean seems to be a logical sequence.

TABLE VIII

THE PERCENTAGES OF CALCIUM AND MAGNESIUM IN CALCIUM- AND MAGNESIUM-BEARING MINERALS, CHARACTERISTIC OF DYNAMIC METAMORPHISM

Mineral	Ca	Mg	
Actinolite	9.5	13.5	Variable
Anthophyllite	0.20	28.69	Variable
Augite	11.4	8.6	Variable
Biotite	.....	14.3	Variable
Chlorite	.....	20.0	Variable
Cordierite	.....	6.1	
Hornblende	8.7	8.64	
Serpentine	.....	25.8	
Spinel	.....	11.5	
Scapolite	9.2	.....	
Tourmaline	1.14	8.9	Variable
Tremolite	9.7	14.9	Variable
Vesuvianite	25.4	1.57	Variable
Wollastonite	34.6	.....	
Zoisite	17.6	.....	

TABLE IX

DYNAMIC METAMORPHISM

Rock	Ca/Mg Original Rock	Ca/Mg Altered Rock	
Average of 12 clays and soils	1.5	....	Clarke, *Bull. 168, U.S.G.S.*, 1900, p. 296
Average of 78 shales	....	1.1	Clarke, *Bull. 330, U.S.G.S.*, 1908, p. 27
Average of 9 slates of Vermont	....	.25	Van Hise, *Mon. 47, U.S.G.S.*, 1904, p. 895
Dolomite	1.5	.03	*Mon. 46, U.S.G.S.* Altered to talc schist, pp. 215–222
Average	1.5	.66	
Gabbro	.95	.44	*Bull. 62, U.S.G.S.*, p. 76
Gabbro	.95	.10	*Bull. 62, U.S.G.S.*, p. 76. Altered more than preceding case
Greenstone	1.19	1.05	*Bull. 62, U.S.G.S.*, p. 91
Gabbro diorite	1.45	.89	*Bull. 62, U.S.G.S.*, p. 89
Average	1.13	.62	

Materials lost by contact metamorphism.—Contact metamorphism of the sediments tends to develop minerals of complex constitution and high specific gravity. The materials in excess of the requirements for the development of adapted minerals tend to be removed, and in part may reach the sea. The relative

instability of calcium at contacts as compared with magnesium is suggested by the tendency toward increase in the magnesium content of altered sediments, as compared with their unaltered equivalents. See Tables X, XI, XII. The averages of the tables are misleading since they do not represent the tendency of the majority of cases.

TABLE X

CONTACT METAMORPHISM OF SLATES BY ACID INTRUSIVES

Rock	Ca/Mg Fresh Rock	Ca/Mg Altered Rock	
Chloritic phyllite	0.13	0.22	Altered by granite (*Neues Jahrb.*, 1897, p. 156)
Slate	0.18	0.05	Altered by hornblende granite 50′ from contact (Hawes, *Am. Jour. Sc.*, Mt. Willard, N.H.)
Slate	0.18	0.14	Ditto, 15′ from the contact
Slate	0.18	2.3	Ditto, 1′ from the contact
Slate	0.18	2.1	Ditto, at contact
Yaqui Gulch	0.39	0.87	Contact with quartz diorite (*Bull. 150, U.S.G.S.*)
Morenci shales	0.82	0.55	Contact with porphyry (*Bull. 229, U.S.G.S.*, p. 348)
Composite	0.62	0.38	Of 6 slates by acid intrusives
Average	0.33	0.37	

TABLE XI

CONTACT METAMORPHISM OF SLATES BY BASIC INTRUSIVES

Rock	Ca/Mg Fresh Rock	Ca/Mg Altered Rock	
Composite	.88	.36	8 adinoles altered by diabase (Roth, *Geol.*, III)
Lenneschiefer	.49	.56	Composite of 3 slates altered by diabase (*ibid.*)
Lenneschiefer	.55	.30	*Ibid.*, 147
Slates	.09	.47	Composite of 3 slates altered by dolerite (*Crystal Falls, Mon. 36, U.S.G.S.*)
Slates	.19	.32	Clausthal altered by diabase dikes (Groddeck, *Jahrb. der königlich-preuss. Landesanstalt*, 1855, pp. 1–53)
Virginia	.04	.34	By gabbro intrusive (*Mon. 43, U.S.G.S.*, 170)
Carboniferous	5.1	10.	Shale by peridotite dike (*Bull. 348, U.S.G.S.*, 343)
Average	1.04	1.75	

TABLE XII

LIMESTONE CONTACT METAMORPHISM

Rock	Ca/Mg Fresh Rock	Ca/Mg Altered Rock	
Homestake	12.7	1.01	By andesite (Leith and Harder, "Utah: The Iron Ores of the Iron Springs," *Dist. Bull. 338, U.S.G.S.*)
White Knob	18.4	74.0	By acid intrusive (Kemp, "Idaho," *Eco. Geol.*, II, 1907)
Morenci	3.98	1.03	Altered by porphyry (*Eco. Geol.*, II, 6, 1907)
Bingham	54	34	Altered by porphyry (*Prof. Paper 28, U.S.G.S.*)
Bingham	13.2	.39	Altered by porphyry (*ibid.*)
Chanarchillo	2.5	.57	Chile, altered by greenstone (Woesta, *Ueber das Vorkommen der Chlor. Jod. Brom. Verbindungen in der Natur*, Marburg, 1870)
Slightly altered limestone	7.4	2.3	F. D. Adams, *Jour. Geol.*, XVII (1909)
Slightly altered limestone	7.4	1.5	*Ibid.*

Materials lost from rocks by hot solutions.—The alteration of rocks by hot solutions along fissures also shows a marked tendency toward rapid removal of lime, and a much slower rate for the removal of magnesium. In some cases calcite, epidote, and other lime-bearing minerals develop in basic igneous rocks, but often calcium is practically absent from the secondary minerals. The compilation on page 399 has been made showing the calcium and magnesium ratio of fresh and altered rocks adjacent to ore-bearing fissures.

Résumé of calcium and magnesium in the products of metamorphism.—The data on metamorphism which have been presented indicate that the percentage loss of calcium which rocks sustain through metamorphic processes tends to be higher than that of magnesium. In fact, it could be shown that the percentage of calcium lost tends to be higher than that of any other element. Exceptions are noted, of course. In view of this tendency, Salisbury's[1] estimate that the disintegration of 55,000,000 cubic miles of average igneous rock would yield the common salt of the sea, while the disruption of three or more times as much rock would be required to yield the limestones, is suggestive.

[1] R. D. Salisbury, "The Mineral Matter of the Sea," *Jour. Geol.*, XIII, 476–77.

TABLE XIII

THE CALCIUM MAGNESIUM RATIO OF FRESH ROCKS AND THEIR EQUIVALENTS ALTERED BY HOT SOLUTIONS ADJACENT TO ORE-BEARING FISSURES

Rock	Ca/Mg Fresh Rock	Ca/Mg Altered Rock	
Granite	1.06	.18	West Australia, Pilbara, Goldfield. Quoted by Lindgren, *Eco. Geol.*, I, 540
Amphibole schist	1.50	1.5	Kalgoorlie, West Australia. Quoted by Lindgren, *ibid.*, 530–44
Granite	1.50	67.	Lindgren and Ransome, "Cripple Creek," *Col. P.P. 54, U.S.G.S.*, 194
Phonolite	5.40	2.4	Ditto
Granodiorite	1.94	5.0	Lindgren, "Placer Co. Cal.," *A.I.M.E.* (1901), 586–87
Amphibole schist	.34	1.7	Ditto
Limestone	116.	17.1	Limestone altered by hot springs. Spurr, "Aspen, Colo.," *Mon. 31, U.S.G.S.*, 210
Andesite	1.64	.35	J. E. Spurr, "No. 2 Tonopah," *Nev. P.P. 42*, p. 216
	.....	.67	J. E. Spurr, "No. 3 Tonopah," *ibid.*
	.....	.35	J. E. Spurr, "No. 4 Tonopah," *ibid.*
	.....	.54	J. E. Spurr, "No. 5 Tonopah," *ibid.*
	.....	.57	J. E. Spurr, "No. 6 Tonopah," *ibid.*
	.....	.28	J. E. Spurr, "No. 7 Tonopah," *ibid.*
	.....	.00	J. E. Spurr, "No. 8 Tonopah," *ibid.*
Monzonite porphyry	2.1	.17	Lindgren, "Clifton-Morenci," *P.P. 43*, pp. 168–69
	.....	.24	Ditto, No. 3
	.....	.09	Ditto, No. 4
	.....	5.1	Ditto, No. 5
Monzonite porphyry	1.4	3.2	Boutwell, "Bingham District," *P.P. 38*, p. 178
Diorite	1.4	1.03	"Willow Creek District, Idaho," *20 Ann. Rept. U.S.G.S.*, Pt. III, 211–32
Hornblende andesite	2.59	2.71	"No. 3, Hauraki Gold Fields," *Eco. Geol.*, IV (1909), 637
Hornblende dacite	2.67	−2.86	"No. 2, Hauraki Gold Fields," *ibid.*, 638
Butte granite	1.05	.62	"No. 2, Sericitized Granite," unpublished investigation, University of Wisconsin
Butte granite	1.05	.53	"No. 8, Granite Mineralized," unpublished investigation, University of Wisconsin
Butte granite	1.05	.77	"No. 9, Hard Silicified Granite," unpublished investigation, University of Wisconsin

If is obvious that if metamorphism continued until all rocks were separated into end products, the residuals remaining in place and the materials lost transported to the sea, it would result in a running down of the calcium content of the lands, and a relative increase in magnesium.

In the deep zones of high pressure and temperature, where there is only slight mobility of the residual materials, this result may be reached and perpetuated for a long time until, in the course of geologic ages, they finally become the shallow zones of low temperature and pressure. Here the residuals of metamorphic processes as well as the materials lost are forever in a state of motion in response to the movements of the atmosphere and the hydrosphere, controlled by gravity and the sun. Thus the products of metamorphism are redistributed into the sedimentary rocks, and these in turn are reworked and redistributed. In this redistribution lies the potentiality of an increase of the ratio of calcium to magnesium of the lands with geologic time.

Has sedimentation increased the ratio of calcium to magnesium of the lands during geologic time?

The sedimentary rocks are derived from other sediments and from igneous rocks, ultimately they are derived from igneous rocks. Clarke's average igneous rock is generally accepted as representing the approximate composition of the primitive lithosphere. The criticism may be offered that this average is necessarily not based on a study of the volumetric importance of the various igneous rock types in the primitive lithosphere. It has also been maintained that the igneous rocks themselves are very largely derived from the fusion of sediments, which may be so but has not been proven. The recurrence of certain predominant igneous rock types at various times and places suggests that the composition of magmas has not been materially influenced in the way which one would expect from regional subfusion of sediments. It seems probable that the primitive lithosphere had a composition between rhyolite and basalt, which is expressed in Clarke's average. Approximations, not finalities, seem all that can be hoped for in this problem.

By an ingenious graphic method, W. J. Mead[1] estimates that the average igneous rock is equivalent to shales, sandstones, and limestones of Clarke's average compositions in the ratio of 80:11:9.

F. W. Clarke[2] has made a similar estimate, based on average

[1] W. J. Mead, "Redistribution of the Elements in the Formation of Sedimentary Rocks," *Jour. Geol.*, XV (1906), 238.

[2] F. W. Clarke, "Data of Geochemistry," *Bull. 330, U.S.G.S.* (1908).

chemical compositions, in which he distributes the average igneous rocks into shales, sandstones, and limestones in the ratio of 80:15:5.

An earlier estimate by Van Hise[1] divides the sedimentary rocks into 65 per cent shales, 30 per cent sandstones, and 5 per cent limestones.

A computation made by myself, using Mead's method, shows that a composite Georgia[2] granite made from Watson's analyses is nearly equivalent to a mixture of composite Georgia clay (Watson's) and average sandstone (Clarke's) in the ratio of 55:45, not enough lime and magnesia being present to be available for limestone. Another computation by myself shows that a composite basic rock made up from composites of diabase, gabbro, basalt, and peridotite in the ratio of 6:6; 6:1 is equivalent to average shale and limestone (Clarke's) in the ratio of 88:12. The upshot of all these computations and estimates seems to be that the predominant igneous rock types are equivalent to a large percentage of clastics, predominantly mud or shale, and a relatively small percentage of limestone, hence the same would be true of the primitive lithosphere, regardless of whether it was entirely rhyolite or entirely basalt.

Under the theory of the stability of oceanic and continental segments, the redistribution of the primitive lithosphere into sediments may have taken place along one or the other of two uniformitarian directions. The redistribution materials may have been deposited upon the continents and in the oceans in such proportions as to leave the composition of the lands unchanged. This might be termed "integral" redistribution, because it leaves the composition of the lands as a whole as it was before. Obviously "integral" redistribution of the redistribution materials to the nth power would not change the composition of the lands. But redistribution has certainly changed the composition of the lands with respect to one element at least—sodium. That the lands contain less sodium now than in the past, in consequence of leaching and the accumulation of non-sodiferous sediments on the

[1] C. R. Van Hise, "Treatise on Metamorphism," *Mon. U.S.G.S.*, XLVII (1904), 940.

[2] Watson, *Bull. No. 9-A, Geol. Survey of Georgia.*

lands, is clearly shown by Becker[1] in his recent contribution, "The Age of the Earth."

Instead of leaving the composition of the lands as before, redistribution might result in a selective withdrawal of certain elements from the lands and possibly the retention of others. This may be termed "selective" redistribution. Redistribution has been selective with respect to sodium, resulting in a progressive decline in the contribution of sodium from the lands to the sea. It probably has been selective with respect to potassium, causing only a slight accumulation of potassium in the sea as compared with sodium. The question is raised here whether selective redistribution may not have caused an actual progressive increase in the calcium content of the lands and a correlative progressive decrease in magnesium, which in turn may have been connected with a similar progressive change in the ratio of calcium and magnesium contributed to the sea, and of the calcium and magnesium carbonates deposited in the sea. It has been pointed out that regardless of whether the primary lithosphere was rhyolite or basalt, redistribution would result in a large proportion of clastics, predominantly mud, and a small proportion of limestone. If redistribution has been integral with respect to clastics and limestones, it would follow that the sediments exposed on the continents are predominantly clastics and subordinately limestones. This test will be applied here to the continental interiors, the continental margins, the epicontinental seas and the deep seas, so far as the progress of my studies permits.

The geologic record of the continental interiors.—The greater portion of the surface of the lands consists of sediments. Major Tillo[2] estimates that the Archaean and younger eruptives constitute only 24.3 per cent of the known area of the continents. It follows from obvious reasons that the greater part of the calcium and magnesium now being delivered to the sea by the rivers comes from the sediments exposed on the lands, and the proportions of calcium and magnesium in the rivers will be roughly proportional

[1] G. F. Becker, "The Age of the Earth," *Smithsonian Inst. Miscellaneous Collections*, LVI (1910), No. 6.

[2] Quoted from Berghaus' *Atlas der Geologie* (1892).

to the amount of calcium and magnesium in the sediments and to the relative solubility of calcium- and magnesium-bearing minerals in the sediments.

In his discussion of "The Metamorphic Cycle," C. K. Leith[1] says:

> Averages of sections made from field observations give uniformly a lower[2] percentage of shales and higher of limestones. An average of twenty-one sections from different parts of the United States shows thirty per cent of limestone. If the difference of proportion determined by the chemical[3] and field methods is a real one, as inspection of the data seems to indicate, the significant questions are raised, (1) whether there may not be a concentration of limestones on the continental areas, their complimentary shales and muds being in the deep sea, (2) whether limestone may not be concentrated in the upper, observed part of the lithosphere, because of its known inability to remain in the deep seated zones of high pressure and temperature.

That the Paleozoic sediments of the Mississippi Valley show a surprising concentration of limestones amounting to from 23.6 to 66.6 per cent of the sections averaged and a marked deficiency of shales and sandstones is brought out in an admirable study made by Miss F. W. Carter.[4] The results of this study are compiled in Table XIV.

TABLE XIV

TABLE SHOWING THE RELATIVE PROPORTIONS OF LIMESTONES, SHALES, AND SANDSTONE IN THE PALEOZOIC OF THE MISSISSIPPI

State	Limestone	Shale	Sandstone
Pennsylvania	23.6	47	25
Alabama	41.3	23	35.5
Ohio	33.2	41.4	23.6
Michigan	42.2	38.3	19.1
Indiana	39	30.3	30.6
Wisconsin	52	38.3	9.5
Minnesota	50.9	40.4	11.5
Iowa	61.1	29.1	9.7
Missouri	66.6	22.8	10.4
Oklahoma	31.7	52.2	16.7
Colorado—eastern	27.5	4.8	57.6
Colorado—central	57	20.9	21.9

[1] C. K. Leith, "The Metamorphic Cycle," *Jour. Geol.*, XV (1907), 304.

[2] Lower than the percentage gotten by distributing an average igneous rock into average sediments.

[3] The chemical method of W. J. Mead (*op. cit.*).

[4] Unpublished thesis (1910), University of Wisconsin.

The composition of the limestones of the Paleozoic of the Mississippi Valley averages that of magnesian limestones, with a lime percentage higher than that of a normal dolomite.

The unconformities in the Paleozoic of the Mississippi Valley represent the removal or lack of deposition of both limestones and clastics, mostly clastics, as follows from the compilation below, also made by Miss Carter (Table XV). Both sedimentation and erosion seem to have worked hand in hand toward the concentration of limestones.

TABLE XV

TABLE OF UNCONFORMITIES IN THE PALEOZOIC OF THE MISSISSIPPI VALLEY

Location	Extent	Kind of Rock Eroded	Amount Eroded	Summary
First base of St. Peter sandstone	Widespread	Limestone L. magnesian	Less than one-half thickness	Took off limestone
Second base Maquoketa shale	Widespread	Galena limestone	Negligible	
Third top of Silurian	Widespread	Salina and Niagara limestone	Slight	
Fourth top of Mississippian	Widespread	Limestones and shales	Much	
Fifth ever since Carboniferous	Widespread	Shale, sandstone, and some limestone	More than preceding combined	Took off more clastics than limestones in preceding

It seems to follow that the sediments of the Mississippi Valley were either derived from sediments already high in limestones, or else the complementary muds have been carried elsewhere, to the margins of the continents perhaps. But even granted that they were derived from sediments high in limestones, it is difficult to escape from the conclusion that ultimately redistribution was selective. Concentration of limestones on the lands began somewhere at some time. A selective withdrawal of muds from the continents began somehow, for the Paleozoic sediments of the Mississippi Valley show a proportion of limestones far in excess of the proportions gotten by redistributing either rhyolite or basalt, the two dominant magmatic differentiates.

A remarkable preponderance of limestone is also evident from

the following averages made from sections in the interior of China, described by Blackwelder in *Researches in China*.

Section	Shales	Sandstone	Limestone	Unknown
	Per cent	Per cent	Per cent	Per cent
Sinian system, Shantung, Northeastern China (Cambro-ordovician, unconformity on limestone)	14	...	86	
Shantung (Carboniferous)	71	...	29	
Shantung, Permo-Mesozoic	36	40	....	24
Shansi-Wu-Tai District. Average of Paleozoic (unconformity on limestone)	Clastics 19.5	...	80.5	
Eastern Ssi Chuan and Lower Yang Tzi Gorges. Paleozoic section (unconformity on top of upper Carboniferous limestone)	17.6	6.5	75.6	

The continent of Europe shows a similar dominance of limestones over clastics. In the southern province of sedimentation, the record is nearly continuous from the Cambrian to the Pliocene, and presents a proportion of limestones far in excess of the ratio gotten by distributing an average igneous rock into the sediments.

Another peculiarity of the sediments on the continental interiors is that they are generally less disturbed and less anamorphosed than the sediments on the margins of the continents. The marginal distribution of mountain ranges and volcanoes harmonizes with this generalization. The fact that the sediments of the continental interiors are generally less anamorphosed than those of the margins is significant in regard to their chemical denudation. Anamorphism tends to cause the decomposition of carbonates and the development of complex silicates, but the silicates are less easily dissolved, hence the relatively small amount of anamorphism of these sediments increases their importance as sources of calcium and magnesium in river waters.

Taking the lime and magnesia contents of Clarke's average sediments merely as objects of illustration, the following table suggests how important the concentration of limestone on the continents may be in changing the ratio of calcium and magnesium in the river waters from what it would be if the lands had the composition either of an average igneous rock, rhyolite or basalt.

TABLE XVI

Rock	Percentage CaO	Percentage MgO	Ratio CaO:MgO	Percentage of Average Sediment (Mead)	Percentages of Paleozoic Sediments of Missouri (Carter)
Shales (Clarke)	3.11	2.44	1.2:1	80	22.8
Sandstone (Clarke)	5.50	1.16	4.7:1	11	10.4
Limestone (Clarke)	42.57	7.89	5.3:1	9	66.6
Average igneous rock (Clarke)	4.79	2.39	1.4:1	..	....
Rhyolite (Osann)	1.43	.38	3.7:1	..	....
Basalt (Osann)	8.91	6.03	1.4:1	..	....

The ratio of lime to magnesia in the average sediment is about the same as in the average igneous rock, 1.4:1. The ratio of lime to magnesia in the Paleozoic sediments of Missouri would be about 4:1 if their composition is like that of Clarke's average sediments. The numerical values are not positive, but they point to the probability that the concentration of limestones on the continental interiors may have had a surprising effect on the lime and magnesia content of river waters, and ultimately on the chemical deposits of the sea.

The record of continental margins.—Chamberlin[1] has pointed out that the sediments which fringe the margins of the continents are characterized by a greater number of unconformities and more intense metamorphism than the sediments of the continental interiors. The imperfections of the marginal record therefore make it impossible to make a fair comparison between the limestone content of the marginal sedimentary column and that of the continental interiors. It is perhaps significant that the marginal sediments of late Tertiary and more recent times are predominantly clastic, which suggests a synchronous relation between continental expansion and the deposition of clastics.

Deposition within the 100-fathom line during continental expansion.—It is significant that in the present geologic epoch of continental expansion, the area of the epicontinental sea is limited to about 10,000,000 square miles, perhaps less than a third of what it has been during periods of great marine expansion. It is also significant that the present period of continental expansion

[1] T. C. Chamberlin, *Geology*, III, 526.

is not favorable to limestone building in epicontinental seas. The preponderance of clastics now forming on the shallows surrounding the lands is such that the sediments within the 100-fathom line are generally spoken of as consisting entirely of muds and sands, although important limestone-building areas are found around Florida, Yucatan, and on the Australian Great Barrier reef. The dominance of clastics seems to be related to climatic conditions and the rejuvenation of streams which has accompanied the rejuvenation of the lands. But shallow, epicontinental seas in times past have been important areas of limestone deposition when their expanse was greater than now.

Deposition beyond the 100-fathom line.—The area of the ocean is estimated by Murray as 143,259,300 square miles. The littoral and shallow-water zones comprise about 10,062,500 square miles, consequently the deep-sea area covers about 133,186,800 square miles. The calcareous deep-sea deposits of terrigenous origin, coral muds, and coral sands have an area of about 2,556,800 square miles or about 1.9 per cent of the deep-sea area. Of the pelagic deep-sea calcareous deposits, the globigerina ooze comprises 49,520 square miles, pteropod ooze 400,000 square miles, or a total of 49,920,000 square miles, 37 per cent of the deep-sea area. The total area of deep-sea calcareous deposits thus constitutes about 39 per cent of the deep-sea area.

The terrigenous non-calcareous muds have a total area of about 16,050,000 square miles, or about 11 per cent of the deep sea. The pelagic non-calcareous deposits have an area of about 64,670,000 square miles, approximately 48 per cent of the area of the deep sea, of which red clay represents 51,500,000 square miles and diatom ooze 10,880,000 square miles. In total, the non-calcareous deep-sea deposits cover about 59 per cent of the deep-sea area.

The content of calcium and magnesium in samples of deep-sea deposits collected by the Challenger expedition has been compiled in Table XVII.

It shows that calcium is more abundant than magnesium, the ratio of calcium to magnesium being about 13:1. The report on deep-sea deposits by the Challenger expedition concludes that the average calcium carbonate content of the deep-sea bottom is about

TABLE XVII

Deposit	Mean Depth Fathoms	Ratio of Calcium to Magnesium	Magnesium Percentage	Calcium Percentage	Approximate Percentage of Area of Ocean Bottom
Coral sand	176	19.2:1	1.8	34.6	coral ss and muds 1.40
Green sand	440	30:	.64	20.0	.59
Green mud	513			10.20	
Red mud	623	43:1	.64	19.55	.07
Coral mud	740	.....	....	34.2	.....
Vocanic muds	1,033	.....	....	8.15	.42
Volcanic sands		16:1	.99	16.03	
Pteropod ooze	1,044	76:1	.42	32.2	.28
Blue mud	1,411	4.7:1	.56	2.71	10.00
Diatom ooze	1,477	28:1	.32	9.17	7.00
Globigerina ooze	1,996	19:1	1.38	26.3	34.50
Radiolarian ooze	2,094	2:1	1.84	4.19	1.00
Red clay	3,730	5:1	.70	3.48	36.00
					92.66

37 per cent, of which fully 90 per cent is derived from the remains of calcareous organisms living near the surface of the sea. However, the 37 per cent calcium carbonate at the sea bottom merely represents the difference between solution and deposition. Solution of the calcareous remains according to the Challenger report is a very important process, resulting principally from the generation of carbonic acid by the decay of the dead organisms.

It is to this fact that the decrease in calcium carbonate with depth is supposed to be due. See Tables XVII and XVIII.

TABLE XVIII

TABLE SHOWING RELATION OF $CaCO_3$ TO DEPTH OF WATER, TAKEN FROM CHALLENGER REPORT

	Average Percentage
14 cases under 500 fathoms	$CaCO_3$ 86.04
7 " from 500 to 1,000 "	$CaCO_3$ 66.86
24 " " 1,000 to 1,500 "	$CaCO_3$ 70.87
42 " " 1,500 to 2,000 "	$CaCO_3$ 69.55
68 " " 2,000 to 2,500 "	$CaCO_3$ 46.73
65 " " 2,500 to 3,000 "	$CaCO_3$ 17.36
8 " " 3,000 to 3,500 "	$CaCO_3$ .88
2 " " 3,500 to 4,000 "	$CaCO_3$ .00
1 " over 4,000 "	$CaCO_3$ trace

The calcium content of the ocean is a variable controlled by its solution and deposition in the ocean and its introduction from the lands. It is therefore barely possible that calcium is now accumulating in the sea, partly from direct chemical reasons, the calcium content of the ocean being below the saturation point, and partly because the shallow-water area, most conducive to the biochemical deposition of calcium carbonate, is relatively limited during the present epoch of continental expansion; and partly because the shallow waters bordering the continents are now considerably polluted by mud and other land débris which depreciates the shore zone as a habitat for lime-secreting organisms. Present climatic conditions also restrict the life zones favorable to shallow-water limestone deposition. Murray and Irvine[1] have concluded from experimental evidence that the calcium carbonate of the sea is probably nearly constant in quantity, since the precipitating agents of the sea probably maintain a balance between the introduction and deposition of calcium carbonate, despite the fact that the calcium carbonate content of the sea is below the saturation point. Whether or not calcium carbonate is actually accumulating in the sea seems uncertain, when the wide range of precipitating conditions controlled by the temperature, pressure, and the relative abundance of living and decaying organisms is considered. Nor would annual analyses of sea water give any clue, since it has been estimated that it would require about 680,000 years to accumulate the calcium carbonate now in the sea at the present rate of contribution from the land, a fact which in itself may be significant of the possibilities in this problem. Judging from the selective solubility of calcium carbonate with respect to depth, it seems that the widening of the epicontinental sea to approximately 30,000,000 square miles during the Carboniferous, as estimated by Chamberlin, must have given a tremendous impetus to the deposition of calcium carbonates on these extensive shallows. Here wave agitation might cause mechanical precipitation, and would minimize the carbonic acid content of the waters which might otherwise be influenced by organic decay. Evaporation would tend to cause concentration. Thus in shallow waters,

[1] *Proc. Roy. Soc. Edinburgh*, XVII (1890), 81.

calcium carbonate may become so unstable through these and other causes as to result in direct chemical precipitation as shown by the well-known case described by Willis[1] in the Everglades off the Coast of Florida and that of Lyell[2] in the mouth of the Rhone. In shallow, warm waters near the lands, the deposition of calcium carbonate through lime-secreting organisms is very much more rapid than in deep waters.

While 90 per cent of the accumulations of calcium carbonate on the floor of the present deep sea come from the skeleta of free-swimming organisms which thrived within the photobathic zone in shallow waters, the remains of both the free-swimming and benthos organisms augment the rate of accumulation. Furthermore, the chances for the preservation of skeleta are many times better in shallow water than in the deeps, as shown by the decrease in the calcium carbonate content of marine deposits with depth. In sinking through miles of water, the remains of pelagic organisms often dissolve before reaching the bottom. Not only is there a very clear dependence of abundant limestone deposition on shallows in the present seas, but from the physical evidence of ripple marks, etc., Schuchert concludes that North American Paleozoic limestones were probably all deposited in less than 300 feet of water. The food supply is another very important factor which attracts lime-secreting organisms to warm, clear, shallow seas near the continents.

The activity of the lime-secreting organisms would be further stimulated by the climatic moderation and uniformity which seem to accompany periods of oceanic expansion. The warming of the seas, consonant with oceanic expansion according to Chamberlin's hypothesis, would diminish its capacity for carbonic acid and decrease the solubility of calcium carbonate. But the shallow epicontinental sea, it seems, would be most susceptible to solar heating, hence from a combination of causes, mechanical, physical, chemical, and organic, limestone building in the shallow seas would probably be intensified in more than arithmetical ratio to the increase in the area of shallow water. The total contribution of calcium from the land would be lessened because of the decreased

[1] *Jour. Geol*, I (1893), 512. [2] *Principles of Geology* (12 ed.), I, 426.

area of the lands. Could not a depletion of the calcium carbonate content of the sea result from intensified deposition on the submerged continents? What then? The solubility of the calcium carbonate toward the shallows from the deeps, a process now in operation as shown by the results of the Challenger expedition, would be accelerated. The selective accumulation of limestones on the continents as shown by geologic sections would be consummated.

Significance of the deposition of muds in the ocean basins.—The composition of river muds is variable, depending upon the composition of the lands over which the rivers flow. The longer the delta region of a river, in general, the smaller probably will be the amount of soluble materials in the muds. The Nile and Mississippi muds may be regarded as typical of the larger streams of the world. In an analysis of Mississippi mud[1] the ratio of lime to magnesia is 1.11:1 (Table XIX). The ratio of lime to magnesia in an analysis of Nile[2] mud is 1.82:1.

TABLE XIX

TABLE SHOWING LIME AND MAGNESIA RATIOS OF NILE AND MISSISSIPPI MUDS

	CaO Percentage	MgO Percentage	Ratio of CaO to MgO
Nile mud	4.85	2.64	1.82
Mississippi mud	1.83	1.64	1.11

The analyses of Nile and Mississippi muds show a relatively high content of magnesia, as compared with other sediments. It follows that if any large proportion of muds is lost from the lands through deposition in the ocean basins, it would mean a selective abstraction of magnesia from the lands, considering the quantitative importance of the muds. The ratio of suspended material to total dissolved solids in the Mississippi at Memphis, according to Dole's yearly average, is 2.3:1. Mellard Reed has estimated that the proportion of suspended to dissolved materials in the river waters of the world is 66:33, or 2:1. Approximately one-half of the dissolved material is calcium carbonate. The ratio

[1] By C. H. Stone, *Science*, XXIII (1906), 634.

[2] Analysis D., *Bull. 330, U.S.G.S.*, 429.

of suspended materials or muds to calcium carbonate is about 4.4:1, which argues for a great deficiency in muds in the sediments now forming as compared with the proportion got by distributing average igneous rock under conditions most favorable to the deposition of clastics, namely, the condition of continental expansion. This is in line with the fact that the present lands represent an accumulation of limestones. Of the muds now carried to the sea, the major portion are deposited on the continental shelves, and therefore have the potentiality of again becoming a part of the land surface. J. W. Barrell[1] estimates that from 50 to 70 per cent of the solids brought down to the sea by rivers is deposited within the 100-fathom line. But many of the large world streams, the Amazon, the Congo, Indus, Ganges, and others, have their terminations near the 100-fathom line. Amazon muds have been traced to a distance of 300 miles from the mouth. Barrell estimates that from 20 to 50 per cent of the muds from the rivers are deposited beyond the 100-fathom line, and are thus permanently withdrawn from the lands. This estimate is entirely in harmony with the deficiency of clastics in geologic sections, and with the probable withdrawal of magnesium from the lands, which is registered in the decreasing magnesium content of limestones in going up the geologic time scale. But the loss of muds from the lands may have been even greater in the past, since many large streams in various latitudes have submerged channels which in some cases extend to the edge of the 100-fathom line. On the other hand, the percentage loss of muds undoubtedly was relatively much less during periods of widespread continental submergence. But during such periods, the total mud transported was very much less, owing to the smaller relief of the lands and their floral blanket resulting from the moderate, equitable climatic conditions which appear to have accompanied the expansion of the seas. During such periods, muds were accumulating on the lands, until periods of continental uplift, like the present, accelerate their transportation toward the continental margins and the deep sea.

Does the ratio of calcium to magnesium in the sea show a selective loss of magnesium from the lands with geologic time?—The ratio of calcium to magnesium in the river waters of the world, taking

[1] J. W. Barrell, *Jour. Geol.*, XIV, 346.

Clarke's data, is approximately 6:1. In the ocean, the ratio of calcium to magnesium is 0.35:1. The relative amount of calcium abstracted from sea water is evidently many times greater than that of magnesium. At the present time, a large proportion of the calcium is being deposited in the deep sea, and is thus either temporarily or permanently withdrawn from the land. A very large proportion of the calcium delivered to the sea has, however, been returned to the lands in the form of limestone deposits; in fact there seems to have been a relatively greater return of calcium carbonate to the lands than of the complementary clastics.

In view of the excess of limestone on the lands, it seems highly probable that the high magnesium content of the ocean represents a selective withdrawal of magnesium from the lands during geologic time. This may be one factor which could have caused a decline in the proportion of magnesium contributed to the sea, in the same way as the sodium contribution has declined with geologic time, because of its accumulation in the sea.

Résumé of results of sedimentation and their effect on the ratio of calcium to magnesium of the lands.—1. The marine sediments which are revealed to the geologist on the continental interiors were deposited during periods of widespread continental submergence. It is a significant fact that the sediments on the continental interiors probably represent several times as much limestone as could be gotten by redistributing an average igneous rock, or average rhyolite or basalt. The gain in limestone seems to be due mainly to a loss of the complementary shales and selective deposition of limestones on the continental interiors. The sedimentary mantle covers about three-fourths of the known area of the continents. The ratio of calcium to magnesium in the average igneous rock is about 1.37 to 1 (Clarke). The lowest ratio of calcium to magnesium in any group of limestones in Daly's[1] compilation is 2.93:1, and the maximum 56.32:1. The ratio of calcium to magnesium in Clarke's average limestone is about 5 to 1. The ratio of calcium to magnesium in the average shale (Clarke) is about 1.48 to 1; that of the average sandstone (Clarke), 5.5 to 1. The dominance of sedimentary over Archean and eruptive terranes and the high percentage of limestones over muds

[1] R. A. Daly, *Bull. Geol. Soc. of America*, XX, 153–70.

indicate a higher ratio of calcium to magnesium of the present lands than in the primitive lithosphere.

2. The marginal sediments show a tendency toward more intense anamorphism, a greater number of and more profound unconformities than those of the interior, and a dominance of clastics in those sediments which were deposited during continental expansion. More intense anamorphism[1] of the border sediments involves a selective retention of magnesium in them.

3. Marine sediments on the present continental shelves within the 100-fathom lineconsist predominantly of clastics, from 50 per cent to 70 per cent of the river-borne sediments being deposited here. This seems to afford a fair perspective of the nature of sedimentation during continental expansion.

4. Areally the calcareous deposits constitute a minority of the deep-sea deposits. The rate of accumulation of the terrigenous deep-sea muds is probably vastly greater than that of the calcareous deposits. Furthermore, a considerable portion of the calcareous deposits goes back into solution, and has therefore the potentiality of returning to the lands. The permanent withdrawal of terrigenous muds from the land areas unquestionably exceeds that of calcareous deposits. This selective withdrawal suggests one factor in the causation of the loss of muds from the continental interiors. Since muds not only tend to absorb more magnesium than calcium, but actually show a high magnesium content when compared to other sediments, it is not improbable that the permanent loss of muds from the continents also involves a selective and permanent loss of magnesium.

5. The selective retention of land-derived magnesium in sea water may have been an important factor in causing an increase in the ratio of calcium to magnesium of the lands.

HAS THE RATIO OF CALCIUM TO MAGNESIUM IN THE RIVER WATERS INCREASED WITH GEOLOGIC TIME?

The lands have been shown to represent a higher content of limestone than could have been gotten from the redistribution of the principal igneous rock types which are generally accepted

[1] *Ibid.*, 37, "Dynamic Metamorphism."

as approximating the composition of the primitive lithosphere. In tracing the evolution of the limestones and dolomites to chemical changes in the sea, it is found highly probable that the ratio of calcium to magnesium in the streams is higher at the present time than in the streams of the primitive lands. This will develop from the following considerations.

The influence of the terranes on the calcium magnesium ratio of underground water and streams.—Unfortunately the data on the calcium magnesium ratio of streams and underground water cannot be regarded as a satisfactory basis for correlation with the calcium magnesium ratio of the terranes over which they flow. The chances of error in water analysis and the variability of the composition of streams make a single analysis or even a group of analyses a questionable basis of correlation. The yearly average stream compositions based on daily samples gotten by the United States Geological Survey[1] for the streams of the United States east of the 100th meridian constitute a creditable exception.

Judging by the data available, it seems that underground waters and streams have a higher ratio of calcium to magnesium than the terranes through which they flow. This agrees with the fact that the metamorphism of rocks results generally in a higher percentage loss of calcium than of magnesium. From Orton's[2] figures, the average ratio of calcium to magnesium in the Niagara limestone of Ohio is 1.72. The rock waters as reported by Orton in the Niagara limestone have the following ratios of calcium to magnesium:

LOCALITY	Ca/Mg
Sidney, Ohio	4.0
Celina, Ohio	1.92
Fountain Park, Ohio	3.15
Fountain Park, Ohio	2.52
Plain City	2.55
Harrisburg	2.59

An average of 66 analyses of well waters from sandstones given in *Bull. 4*, of the University of Illinois, yields a ratio of calcium

[1] R. B. Dole, "Water Supply," *Paper 236, U.S.G.S.*

[2] Edw. Orton, *Nineteenth Ann. Rept. U.S.G.S.*, Part 10.

to magnesium of about 2.6. Twenty-four analyses of well water from dolomites gave an average calcium magnesium ratio of 2.3.

None of the crystalline terranes from which stream analyses are reported can be regarded as equivalent in composition to an average igneous rock, in which the ratio of calcium to magnesium is about 1.37 to 1.

The analyses are of unequal value. Only those of the Chippewa and Wisconsin are based on yearly averages. The calcium ratio of the others may be too high or too low. In the following table, the ratio of calcium to magnesium varies from 2.03 to 4.91.

TABLE XX

TABLE SHOWING THE CALCIUM MAGNESIUM RATIO IN STREAMS FLOWING OVER CRYSTALLINE ROCKS

River	Mg	Ca	Source
Arkansas River, Canyon, Colo	1	3.95	Clarke, *Bull. 330, U.S.G.S.*, 59
Pigeon R., Minn.	1	3.14	*Ibid.*, 61
Ottawa R. Low water (*a*)	1	3.50	Daly, *Bull. Geol. Soc. Am.*, XX, 159
Ottawa R. High Water (*b*)	1	3.82	*Ibid.*
Ottawa R. mean (*a*) and (*b*)	1	3.69	*Ibid.*
Ottawa R. (St. Anne)	1	4.91	*Ibid.*
From granite terrane, average 6 analyses	1	3.20	J. Hanamann, "Bohemia," *Archiv. Natur-Landesforschung Böhmen*, IX, No. 4
From mica schist, av. 6 analyses	1	2.48	*Ibid.*, X, No. 5
Wisconsin River	1	2.03	Average of one year. Dole, *W.S. Paper, U.S.G.S.*, 236
Chippewa River	1	2.70	Average of one year. Dole, *W.S. Paper, U.S.G.S.*, 236

The following calcium magnesium ratios of streams on shales and dolomites are based on yearly averages of daily samples reported by Dole.

TABLE XXI

THE CALCIUM MAGNESIUM RATIO IN STREAMS FLOWING OVER DOLOMITE AND SHALES

River	Sample	Mg	Ca	
Fox River, Elgin, Ill.	Niagara dolomite	1	1.70	Average of 1 year
Fox River, Ottawa, Ill.	Niagara dolomite and Cincinnati shale	1	1.87	" " " "

TABLE XXI—*Continued*

River	Sample	Mg	Ca	
Kankakee, Kankakee, Ill.	Niagara dolomite	1	2.76	Average of 1 year
Rock, Rockford, Ill.	Dolomite and shale	1	1.80	" " " "
Rock, Sterling, Ill.	" " "	1	1.80	" " " "
White, Azalia, Ind.	" " "	1	2.65	" " " "
White, Indianapolis, Ind.	" " "	1	2.55	" " " "
Cedar, Cedar Rapids, Ia.	" " "	1	3.00	" " " "
Hudson, Hudson, N.Y.	" " "	1	5.50	" " " "
Wabash, Logansport, Ind.	" " "	1	2.34	" " " "
Wabash, Vincennes, Ind.	" " "	1	2.77	" " " "
Illinois, La Salle, Ill.	" " "	1	2.27	" " " "
Illinois, Peoria, Ill.	" " "	1	2.33	" " " "
Illinois, Kampsville, Ill.	" " "	1	2.35	" " " "
Iowa, Iowa City, Ia.	" " "	1	2.88	" " " "
Maumee, Toledo, O.	" " "	1	3.56	" " " "
Little Vermilion, Streator, Ill.	" " "	1	1.72	" " " "
Little Wabash Carmi, Ill.	" " "	1	2.30	" " " "
Miami, Dayton, O.	" " "	1	2.45	" " " "
Cache, Mounds, Ill.	" " "	1	3.16	" " " "
Big Vermilion, Danville, Ill.	" " "	1	2.16	" " " "
Big Muddy, Murphysboro, Ill.	" " "	1	2.08	" " " "
Embarass, Charleston, Ill.	" " "	1	2.12	" " " "
Embarass, Lawrenceville, Ill.	" " "	1	2.30	" " " "
Grand, Grand Rapids, Mich.	" " "	1	2.94	" " " "
Muskingum, Zanesville, O.	" " "	1	4.52	" " " "
Sangamon, Decatur, Ill.	" " "	1	2.11	" " " "
Sangamon, Springfield, Ill.	" " "	1	2.16	" " " "
Sangamon, Chandlerville, Ill.	" " "	1	2.08	" " " "

The average calcium to magnesium ratio of these streams is between 2.5 and three. The ratio of calcium to magnesium of a normal dolomite is 1.61; that of an average shale 1.47 (Clarke). The calcium to magnesium ratio of the streams is probably higher than that of the terranes through which they flow.

An average of five water analyses on phyllite reported by Hanamann shows a ratio of calcium to magnesium equal to 2.37.

The stream waters from limestone areas show a high calcium ratio. See Table XXII.

TABLE XXII

TABLE SHOWING THE CALCIUM MAGNESIUM RATIO IN STREAMS FLOWING OVER LIMESTONE

River	Mg	Ca	Source
Thames	1	11.6	*Bull. 330, U.S.G.S.*, 75
Meuse, Liège, Belgium	1	10.8	*Ibid.*, 75
Seine at Bercy	1	46.0	*Ibid.*, 76
Loire at Orléans	1	10.7	*Ibid.*, 76
Rhone at Geneva	1	16.8	*Ibid.*, 76
Kentucky River, Frankfort	1	5.5	*Ibid.*, 66
Cumberland at Nashville	1	10.6	*Ibid.*, 66

The following table of averages suggests the influence of the terrane on the run-off.

TABLE XXIII

Terrane	No. of Analyses	Ca/Mg
Limestones	7	15
Phyllites	5	2.37 Hanamann
Crystalline	11	3.36
Dolomites and shales	29	2.91
Sandstone	66	2.6
Dolomite	24	2.3

The influence of climate on the calcium magnesium ratio of streams.—Clarke[1] has pointed out that the streams of humid, more or less forest-covered portions of North America are normally carbonate waters in which calcium is the principal base, while rivers in arid climates tend to be high in sulphates and chlorides in which calcium may or may not be the principal base. The

[1] F. W. Clarke, *Bull. 330, U.S.G.S.*, 72.

magnesium content of streams in arid climates tends to be high, as shown by the following table.

TABLE XXIV

CALCIUM MAGNESIUM RATIO IN STREAMS OF ARID COUNTRIES

Streams	Mg	Ca	Source
Sacramento R., Cal.	1	2.12	Clarke, *Bull. 330, U.S.G.S.*, 70 .
San Lorenzo R., Cal.	1	2.01	*Ibid.*, 70
Santa Clara R., Cal.	1	2.30	*Ibid.*, 70
Mission Creek, Cal.	1	3.83	*Ibid.*, 70
Cold Spring Creek, Cal.	1	3.01	*Ibid.*, 70
Mono Creek, Cal.	1	2.74	*Ibid.*, 70
Santa Ynez R., Gibraltar, Cal.	1	2.93	*Ibid.*, 70
Chelif R., Algeria	1	1.81	*Ibid.*, 70
Chelif R., Algeria	1	1.50	*Ibid.*, 70
Chelif R., Algeria	1	2.88	*Ibid.*, 70
Brazos R., Tex.	1	4.67	*Ibid.*, 69
Rio Grande, Tex.	1	7.20	*Ibid.*, 69
Pecos R., N.M.	1	3.72	*Ibid.*, 69
Colorado River, Yuma, Ariz.	1	3.30	*Ibid.*, 69
Gila River, Ariz.	1	3.17	*Ibid.*, 69
Salt River, Ariz.	1	2.65	*Ibid.*, 69
Colorado R., Austin, Tex.	1	3	Dole, *W.S. Paper 236, U.S.G.S.*, 56
Rio Grande, Laredo, Tex.	1	4.5	*Ibid.*, 96
Brazos, Waco, Tex.	1	6.3	*Ibid.*, 50

Where the terrane is exceptionally calcareous, however, calcium may predominate considerably. The insolubility of lime under arid conditions is illustrated by Hilgard's[1] composite soils, Table XXV.

TABLE XXV

CALCIUM MAGNESIUM RATIO IN SOILS FROM ARID AND HUMID REGIONS

Soil	Mg	Ca
Average of 466 soils from humid regions of southern part of United States	1	.57
Average of 313 soils from arid portions of United States	1	1.15

Apparently soils in arid climates contain about twice as much calcium in proportion to magnesium as those of humid climates.

Influence of the belt of cementation on the calcium magnesium ratio of underground waters.—The materials carried in solution by underground waters in the belt of cementation undergo various abstractions and additions on their way to the sea. The cements

[1] E. W. Hilgard, *Bull. No. 3, U.S. Weather Bureau* (1892), 30.

of the limestones and sandstones undoubtedly contain much more calcium than magnesium, although no estimate of their relative proportions can be given. Since the ratio of calcium to magnesium in the average sandstone (Clarke's) is 5.50 to 1, it is probable that the ratio of calcium to magnesium of the cementing materials in the sandstones is even higher.

The solutions which percolate through shales, clays, and other silicates are known to suffer an exchange of bases and other changes through the interaction of water solutions and silicates. This interaction is dependent upon the condition of chemical equilibrium between the solutions and the silicates. Kiilenberg[1] and other experimenters have shown that soils absorb more potassa and magnesia than lime and soda. The great absorption of potassa by soils and the very slight absorption of soda has been interpreted as the reason why land plants utilize potassa more largely than soda.

TABLE XXVI

RATIO OF CALCIUM TO MAGNESIUM IN THE CHLORIDE WATERS OF THE DEEP COPPER MINES OF MICHIGAN, AS COMPARED WITH THE SURFACE WATER

Deep Mine Waters	Ratio of Ca: Mg
C. and H. vertical shaft	62
Tamarack Junior (very strong)	319
C. and H., 3,000 feet	412
C. and H., 17th level	475
Tamarack, 4,300 feet	(trace of magnesium present)
Trimountain, 9th level	(trace of magnesium present)
Quincy mine (very strong)	4,300
Quincy mine	3,078
Surface water	4.75

The influence of silicates in the belt of cementation on the calcium magnesium ratio of underground waters is suggested by a comparison of the calcium magnesium ratio of the surface and deep waters of the copper mines of Lake Superior. The deep waters are probably the modified residuum left from the cycle of deposition which developed the ores and gangue minerals. The result of cementing processes has been a concentration of calcium in the solutions. Magnesium has evidently been forced out of solution by the conditions of chemical equilibrium. See Table XXVI.

[1] *Mitteil. d. Landw. Centralvereins für Schlesien*, Heft 15, p. 83, quoted by E. C. Sullivan, *Bull. 312, U.S.G.S.*, 16–19.

The relative absorptive power of the crustal materials for calcium and magnesium has not been adequately determined. Certain it is that many shales, slates, muds, and soils have a higher content of magnesium than of calcium. The probability that the selective withdrawal of muds from the lands to the deep sea has involved a selective loss of magnesium from the lands has been pointed out on p. 414.

The average calcium magnesium ratio of the solutions contributed to the sea.—The Mississippi[1] at New Orleans, which may be regarded as a mixture of the waters from the average Paleozoic terrane, shows a ratio of calcium to magnesium of 3.81 to 1. The average calcium to magnesium ratio of 73 streams east of 100th meridian of the United States observed daily at 94 stations for a period of one year is about 4 to 1. In Sir John Murray's well-known composition of 19 streams of the world, the calcium to magnesium ratio is 4.4 to 1. From Mellard Reade's[2] data, the ratio of calcium to magnesium in the materials of chemical denudation is 8.25 to 1. A better based figure for the average composition of the streams of the earth is that recently made by Clarke.[3] The ratio of calcium to magnesium in Clarke's average as previously cited is about 6 to 1.

While the ratio of calcium to magnesium of the solutions contributed to the sea is higher than it would be if the lands had the composition of an average igneous rock, the largest streams do not seem to show the high calcium to magnesium ratio that one would expect from the amount of limestone on the continents. However, the Mississippi is about the only large stream whose composition is accurately determined. It may be that the large amount of suspended material in rivers tends to lower the calcium ratio, since the muds, particularly of humid climates, tend to be high in magnesium. The arid nature of about one-fifth of the land area is another factor which may cause a retention of calcium by the land. If this hypothesis is correct, a compensating increase in the calcium ratio of rivers will be contemporaneous with oceanic expansion.

[1] R. B. Dole, *W.S. Paper 236, U.S.G.S.*, 117.

[2] Mellard Reade, *Chemical Denudation in Relation to Geologic Time* (1879), 1–61.

[3] F. W. Clarke, *Study of Chemical Denudation*, Smithsonian Institution, Vol. LVI (1910), No. 5, p. 8.

Conclusion: Increase of the ratio of calcium to magnesium in rivers with geologic time.—Evidence has been presented to show that the ratio of calcium to magnesium of stream water is influenced primarily by the ratio of calcium to magnesium of the terranes which they drain, being generally higher than that of the terranes.

Climate exerts a modifying influence. Aridity lowers the ratio of calcium to magnesium of the stream waters, causing a concentration of calcium in the soils, while humidity has the opposite effect. The interaction of the salts carried in solution by streams and ground waters with the land materials, particularly those high in clay, results in a greater loss of magnesium from the waters than of calcium, thus tending to increase the ratio of calcium to magnesium of the streams and ground waters.

Regardless of any theory of the origin of the earth, geologic evidence points to the igneous rocks as the primitive source of the sedimentary rocks. The streams of the primitive lithosphere, therefore, probably approached in their chemical character the present streams, flowing over crystalline rocks, subject to climatic and other modifications. Such streams have a ratio of calcium to magnesium approximating 3 to 1. The best figure given for the average calcium to magnesium ratio of the streams of the world is approximately 6 to 1. The latter figure probably should be greater, considering the abundance of limestone on the continents. Little doubt therefore remains that the proportion of calcium to magnesium in the streams is now higher than in earlier stages of the earth's history. It is also highly probable that the increase in the ratio of calcium to magnesium in the rivers has been continuous with geologic time, because of the progressive increase in this ratio in the limestones deposited during geologic time, and because of the selective deposition of limestones on the submerged continents.

STATEMENT OF HYPOTHESIS

The conclusion has been reached that dolomites develop predominantly in the sea rather than by the metamorphism of limestones after their emergence from the sea. Hence the decline in the percentage of dolomite in going up the geologic column seems

to indicate that less and less dolomite was deposited in successive periods of geologic history, thus pointing to a progressive change in the conditions of deposition. Of the four factors controlling the deposition of carbonates in the sea, viz., temperature, pressure, life processes, and chemical composition, only the last two show any probability of progressive change with time. There is no evidence for a change in the nature of life processes. There is evidence for a change in the chemical composition of the sea, specifically for an increase in the ratio of calcium to magnesium contributed to the sea from the lands, which will appear from the following considerations. The present lands contain a much larger proportion of limestones than could be gotten by redistributing a granite or basalt, generally accepted as being equivalent to the materials of the primitive lands. It is inferred from a consideration of the relation between the composition of river waters and the terranes which they drain that the present rivers have a higher ratio of calcium to magnesium than those of the primitive lands.

The accumulation of limestones on the lands of increasing calcium content, with time, seems to be related to a reworking of the land over and over again along certain selective lines. A higher percentage of calcium than of magnesium tends to be lost from all kinds of rocks when subjected to all kinds of metamorphic processes. Hence there is a continuous selective removal of calcium from the lands of the sea, as is evidenced by the fact that the ratio of calcium to magnesium of rivers tends to be higher than the ratio of calcium to magnesium of the lands which they drain. This involves a selective retention of magnesium in the clastics. The transportation and deposition of clastics is at a maximum during periods of continental expansion and at a minimum during periods of continental submergence. The clastics are therefore deposited mainly on the margins of the continents and in the deep sea. Those deposited in the deep sea are permanently lost to the lands and with them goes a selective loss of magnesium from the lands. The carbonates, calcium and magnesium, are deposited mainly in shallow epicontinental seas during periods of continental submergence, in consequence of organic

and inorganic agencies. The percentage of calcium carbonate which is deposited from the sea is higher than that of magnesium carbonate, and from field and laboratory evidence it is inferred that the proportions of the two carbonates deposited are in some direct relation to their proportions in the rivers which bring them to the sea. Hence, there is a selective return of calcium to the lands.

It is therefore inferred that the evolution of the limestones and dolomites has been in response to the gradual increment of calcium over magnesium in the solutions contributed to the sea, a tendency arising primarily from physical-chemical causes, aided or accelerated by organic processes working harmoniously with the inorganic environment.

For illustration, it may be assumed that sedimentation began during continental expansion when the lands had the composition of an average igneous rock. From the known results of metamorphic processes, it would follow that the solutions contributed to the sea had a higher calcium to magnesium ratio than the lands from which they were derived, and that the residuals had a higher proportion of magnesium to calcium than the original rocks. A part of the residuals, particularly the muds, are subject to selective transportation to the continental margin and the deep sea. Accepting the hypothesis of the permanence of oceans and the continents, those deposited in the deep sea are permanently removed from the continents. The calcium and magnesium salts interact with the materials of the ocean bottom and enter into the constitution of silicates, carbonates, and other compounds, or they may interact with other constituents in the water, and be precipitated principally as the carbonates. Magnesium would tend to interact more actively with the muds of the bottom than calcium. Calcium would tend to be more insoluble in shallow water than in the deeps, while the opposite tendency probably characterizes magnesium. Magnesium salts in general are more soluble in sea water than calcium salts. Organic precipitation, apparently only an adaptation to conditions of chemical equilibrium already existing, would be particularly effective in abstracting calcium from warm, shallow seas. The relative solubility of the materials

precipitated would depend upon conditions of equilibrium controlled mainly by temperature, concentration, the amount of carbonic acid in the air and ocean, and organic processes. As a result of the preceding selective influences, the calcium to magnesium ratio of the limestones would tend to be higher than that of the solutions contributed to the sea. However, contemporaneous with continental expansion, as at the present time, limestone deposition would be at a minimum, which might involve a concentration of calcium in the sea until more favorable conditions of precipitation arise. Limited areas of shallow water, vigorous erosion, continental climates, and other supplementary conditions make periods of continental expansion more favorable to the deposition of clastics than limestones.

Gradually the lands waste away, the ocean advances over the continents, partly in consequence of fill from the land, in part, perhaps, as a result of secular earth movements which cause a shallowing of the ocean basins. The rivers carry less and less débris to the sea, and deposit it farther and farther inland from the margin. On the submerged continental areas, covered by shallow seas, which now may be three or more times as extensive as they were during the preceding period of continental expansion, chemical and biochemical processes combine in making this an era of limestone building. From experimental and field evidence, the inference is drawn that *the ratio of calcium to magnesium in the deposited limestones is influenced primarily by their respective rate of contribution from the land, and modified by selective organic and inorganic agencies working to a common end.*

As postulated by Chamberlin, with the expansion of the seas, the zonal, diversified continental climates tending toward aridity and refrigeration yield to more uniform, mild atmospheric conditions. A widening of the life zones favorable to limestone deposition follows. Thus in the Devonian, corals thrived in the now ungenial climate of Hudson Bay. With world-wide climatic moderation, a new condition of equilibrium is established between the carbon dioxide of the sea and air. Warm water absorbs less carbon dioxide than cold. The sea begins to contribute its excess of carbon dioxide to the air, in consequence of which the calcium

of the sea becomes still more insoluble. The atmospheric conditions and the land relief favor the floral blanketing of the earth, thus stimulating chemical denudation and creating an effective screen for the retention of clastic materials on the land.

As the waters again withdraw from the lands into the hollows of the sea in response to secular earth movements, they leave composite sediments behind them whose ratio of calcium to magnesium is higher than that of the average igneous rock. With topographic rejuvenation, the muds are again carried toward the margin and to the deep sea, or possibly at times directly to the deep sea as suggested by submerged stream channels, the continuation of existing streams which in some cases extend to the margin of the deep sea. Various parts of the earth are subjected to regional metamorphism and secular uplift, particularly the continental margins, causing selective removal of calcium and the concentration of magnesium in the residuals. The marginal sediments, dominantly clastics, by virtue of position, relief, and a combination of other factors, are in a most favorable position to be removed from the land and swept into the deep sea, where they would be permanently withdrawn from the land. The deposition of clastics is again at a maximum, that of limestones at a minimum. As the pendulum swings from one extreme to another, it marks a curve of progressive change in the composition of the lands and in the ratio of calcium to magnesium in the salts contributed to the sea, consummated by an accumulation of limestones on the continents of progressively higher calcium content, both a reflex and a cause of changes in the land composition, and by the withdrawal of the complementary muds toward the margins and the deep sea, slow during periods of oceanic expansion, but tremendously accelerated during periods of oceanic retreat, selective concentration of magnesium in the deep zones of high temperature and pressure, in the clastics, and in the sea—a never-ending cycle of selective causes and cumulative effects, recalling the words of Faust:

> Wie alles sich zum Ganzen webt,
> Eins in dem anderen wirkt und lebt.

SUMMARY

The problem under discussion is, Why does the dolomite content of the geologic column decrease with time? Is it due to a secondary alteration of limestone after emergence from the sea, roughly proportional to time, or is it due to a gradual decline in the primary development of dolomite in the sea? If the latter, what factors controlling the deposition of dolomite have changed during geologic time, temperature, pressure, life processes, or the chemical composition of the sea?

The conclusions reached are: dolomite develops predominantly in the sea, therefore the decrease in the dolomite content of the sediments in going up the geologic column is mainly due to a decrease in the proportion of dolomite developed in the sea with time.

The factors of deposition whose progressive change has probably controlled the decline of dolomite development in the sea are life processes and the chemical composition of the sea. There is no definite evidence for a change in the nature of the life processes in their relation to dolomite deposition. There is evidence for a change in the chemical composition of the sea; namely, the fact that the present ratio of calcium to magnesium of the streams is probably more than twice that of streams draining crystalline terranes, comparable in composition to the primitive lands. Accepting uniformitarianism, it follows that the present streams have a much higher ratio of calcium to magnesium than the primitive streams. It has been indicated that solutions high in magnesium and low in calcium are more favorable to the development of dolomite than those which are low in magnesium and high in calcium. It is therefore highly probable that the chemistry of the primitive sea was more favorable to the deposition of dolomite than the present ocean.

The increase in the proportion of calcium to magnesium in the streams is believed to be due to selective processes whose effects have been cumulative with time. Rock alterations tend to result in a higher percentage loss of calcium than of magnesium, the materials lost being largely transported in solution to the sea.

A higher percentage of magnesium is retained in the residuals of rock decay than calcium, but erosive processes are constantly removing the residuals toward the margins of the lands, and during periods of continental expansion a considerable proportion is swept into the deep sea and permanently lost from the lands. In consequence of a combination of organic and inorganic agencies, the maximum deposition of limestones and dolomites is on the submerged lands during periods of oceanic expansion. The percentage of calcium precipitated is higher than that of magnesium, but the proportions of calcium to magnesium which are precipitated bear some direct relation to their ratio in the rivers which bring them to the sea. With the progressive elimination of clastics and magnesium from the lands with geologic time, and in their place the gradual accumulation of calcium in the form of limestone, the proportion of calcium to magnesium contributed by rivers to sea has increased with time.

The writer is indebted to C. K. Leith for suggestions and criticisms.

DIFFERENTIATION OF KEWEENAWAN DIABASES IN THE VICINITY OF LAKE NIPIGON

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In recent numbers of *Economic Geology* two papers have been published describing the differentiation products of the quartz-diabases of the Nipissing District, Ontario.[1] Since these diabases have generally been regarded as of Keweenawan age, certain differentiation products of the Keweenawan diabases in the vicinity of Lake Nipigon are also of interest.

On the north shore of Lake Superior and extending northward beyond Lake Nipigon there are masses of diabase and gabbro which intrude the older crystalline rocks in the form of batholiths, dikes, and bosses and the sediments in the form of the "Logan sills." Although there are differences of opinion regarding the geological age of these rocks, the writer concurs with those who regard, as closely related in origin, the great amygdaloidal basalt flows of Keweenaw Point, the Duluth gabbro, the "Logan sills," the Sudbury Nickel eruptive, and the Cobalt diabases, as well as many other masses of diabase in intervening areas. The great igneous activity of this region seems to have been the result of extensive crustal adjustment centered around Lake Superior and diminishing in intensity as a greater distance from the center was reached. It is probable that on the northern side of the Lake Superior basin the intrusive masses were being injected into sediments which had already been formed while the alternate deposits of sediments and lava flows were being deposited on the south side and that a close relationship exists between all portions of this great series of sediments and extrusive and intrusive igneous rocks.

While a general description of the petrography of these rocks is given here, the object of this paper is to call attention to certain

[1] W. H. Collins, *Econ. Geology*, V, No. 6, p. 538; R. E. Hore, *ibid.*, VI, No. 1, p. 51.

evidences of differentiation which have already been mentioned by Dr. A. P. Coleman and the writer and to add additional notes to the descriptions of this phenomenon.

PETROGRAPHY OF THE DIABASES

The Keweenawan rocks around Lake Superior have been described petrographically in detail, by Irving, Bayley, Van Hise, and many others. In the vicinity of Lake Nipigon the rocks are in many respects similar to those around Lake Superior and they have been described with less detail by Coleman, Wilson, and other geologists. The greater portion of the shores and the islands of this lake consist of basic rock, either diabase or gabbro. Thin sections almost invariably show the ophitic texture more or less well developed, and, although in many places the diabase grades toward gabbro, the greater portion of the rock is diabase. In the sills, diabase always seems to be found, and the same statement may be made of the smaller bodies of the rock, while some of the larger batholithic masses, which have suffered some differentiation, more strongly resemble gabbro.

Structurally the rocks form bosses, large and small, batholiths, or very large irregular masses, dikes, and sills. The dikes are often large, as some were seen in the Onaman Iron Range area 150 ft. in width, and these seem to represent offshoots from the main diabase mass in the vicinity of the lake. The sills, known as the "Logan sills," form beds from two to several hundred feet in thickness. These masses lie between beds of sandstone, shale, or dolomitic limestone, or between these sediments and the underlying Archean rocks, and in all cases studied they present evidence of their intrusive character. Columnar structure is a characteristic of nearly all of the larger masses, especially of the larger sills.

In macroscopical characters these basic rocks generally present a monotonous appearance. They vary in grain from coarse to medium fine and in color from brownish to nearly black. Some of them weather rapidly to granular incoherent masses, and, in the early stages of this weathering, they exhibit in many places cleavage surfaces with a bronze tint. In many cases the ophitic texture is readily recognized in the hand specimen, but in the masses

which tend to become coarse grained and to separate into little aggregations of feldspar and magnetite this texture is lost to a large extent and the rock becomes more like a coarse gabbro. In one place on the shore of Lake Nipigon some sand was collected which showed poikilitic texture where feldspars were inclosed in augite.

In microscopical observations these rocks usually show labradorite, augite, or diopside, and ilmenite or magnetite. Olivine is widespread but is not always present and in specimens without olivine quartz has been found, but it is lacking in many specimens. Biotite appears in small quantities and titanite was found in one section. Since the latter mineral occurs near a dike of acid rock and is not commonly developed in diabases or gabbro, it is believed to be due to the influence of this dike, as some of these acid dikes carry titanite.

Although these rocks are on the whole comparatively fresh, certain alteration products occur. The olivine frequently shows serpentine and iron oxide as alteration products, and the augite and diopside, although usually quite fresh, often contain secondary amphiboles and actinolite. In a specimen from "Haystack Mountain," north of Lake Nipigon, a crystal of magnetite occurs partially surrounded by a mass of actinolite needles which, on revolving the stage of the microscope, show rotary extinction (Fig. 1). These needles seem to be the product of alteration of an augite crystal whose growth began around the magnetite and they resemble similar fibrous growths which W. S. Bayley describes as occurring around magnetite in the basic rocks of the Lake Superior region, although he does not ascribe a secondary origin to them.[1] In a specimen from the shore of Lake Nipigon, opposite "Two Mountain" Island, the diopside and magnetite are intergrown to some extent and the latter sometimes occurs as a fringe along the border of crystals of the former. Although much of the magnetite associated with the

FIG. 1.—Magnetite partially surrounded by augite which has altered to actinolite needles (greatly enlarged).

[1] *Journal of Geology*, I, 702–10.

diopside is primary, some crystals of the diopside which are partially altered to secondary amphiboles contain also undoubted evidence of alteration to magnetite and hematite. While these are unusual alteration products for diopside, analyses of this mineral from gabbro sometimes show as much as 15 per cent of

FIG. 2.—Photomicrograph of diabase showing ophitic texture (crossed nicols; ×40).

iron oxide. The pyroxene is readily recognized as diopside by its characteristic color and extinction angles.

In texture the ophitic character is usually well developed, as the labradorite generally occurs as lath-shaped, nearly euhedral crystals, which penetrate the augite and diopside (Fig. 2) and in some cases are surrounded by them, giving also a poikilitic texture. The rock might therefore be called, to apply the term suggested

by A. N. Winchell for such textures, a poikilophitic rock.[1] In sections of diabase from "Haystack Mountain" the augite is frequently twinned with two members, and instead of the usual stout crystal it occurs in long, narrow forms, somewhat lath shaped, and in this respect resembling the feldspars.

DIFFERENTIATION PRODUCTS; PEGMATITE DIKES

The differentiation products of the Keweenawan rocks of the Lake Superior region have been frequently mentioned. Clements states that the gabbro in Minnesota shows undoubted evidence of differentiation in the large masses of anorthosite and the patches of magnetite and titaniferous iron ore.[2] W. S. Bayley describes peridotites and pyroxenites as very basic phases of the gabbro in his description of the Lake Superior region.[3]

From Lake Nipigon A. P. Coleman describes picrite and other very basic phases of the diabase and also certain acid dikes which are described as post-Keweenawan but closely related to the Keweenawan basic rocks and perhaps differentiation products of them.[4] These rocks are described as having a pegmatitic or micropegmatitic texture and as having the composition of granite or granodiorite.

In "Haystack Mountain" north of Lake Nipigon the writer found similar dikes and from their relationships suggested that they represented an acid phase of the diabase magma.[5] The later observation of similar dikes in the Duluth gabbro near Duluth, Minnesota, confirmed the belief that these rocks are differentiation products of the diabases and gabbros.

The rock at "Haystack Mountain" is a coarse diabase, rather gabbro-like, and shows small, dark patches of titaniferous magnetite and in places lighter blotches consisting largely of feldspar. The magnetite is sufficiently abundant in part of the hill to influence the compass so that prospectors were led to record mining claims

[1] "Use of 'Ophitic' and Related Terms in Petrography," *Bull. Geol. Soc. Am.*, XX (1910), 661–67.

[2] *U.S. Geol. Survey, Monograph XLV*, 397–424.

[3] *Jour. of Geology*, II (1894), 814–25.

[4] *Bureau of Mines of Ontario*, XVII (1908), 163–64.

[5] *Ibid.*, XVIII (1907), 162.

upon it. Besides these small segregations of feldspar there are irregular dike-like masses of similar, light-colored rock and a few fairly distinct dikes, all of small size and varying from one-half inch to a foot in width. These dikes are rather fine grained and in thin section show the following characters. The texture is usually micropegmatitic and one section is composed of about 60 per cent feldspar, 30 per cent quartz, 10 per cent hornblende, and a little magnetite and hematite. The feldspar is chiefly orthoclase with a little albite and the rock is a granite. Another section contains very little hornblende and a little epidote, the rock being composed almost entirely of feldspar in the proportions of 65 parts orthoclase to 35 parts plagioclase. This rock is a syenite grading toward a monzonite. Still another section is from a dike which might be regarded as a monzonite. It contains a little enstatite, epidote, and titanite, while the greater portion of the rock is feldspar and in the proportions of about 66 per cent albite and oligoclase and 34 per cent orthoclase. A fourth section is from an augite-syenite dike in which the orthoclase makes up 75 per cent and the sodic variety 25 per cent of the feldspar. There are a good many small augite crystals and the micropegmatitic texture is well developed. A section of a dike from near "Two Mountain" Island is also an augite-syenite.

The most interesting dikes in the region are those occurring on Flat Rock Portage near the south end of Lake Nipigon. At this point a large mass of rock, described by Coleman as a sill of epi-basalt or fine-grained diabase-porphyrite, is cut by a pegmatite dike varying in width from three inches to one foot. Where the diabase has suffered columnar jointing the fissures have filled with acid rock similar to the flesh-colored or pink dikes described above (Fig. 4). The surface of this sill is flat and fine grained, and when the glacier passed over it interesting chatter-marks were left. The pegmatite dike is medium coarse grained, flesh colored, and appears to be composed very largely of feldspar. Under the microscope the pegmatitic intergrowth of various minerals and the graphic intergrowth of quartz and feldspar are well developed. The rock consists of quartz in proportion of 10 per cent, epidote 10 per cent, and sodium-calcium feldspar 80 per cent. The

feldspars show a wonderful development of the zonal structure (Fig. 3). In the rapid growth of the crystals the zones of calcium- and sodium-rich material have developed mostly at their ends, and they have thus been drawn out to excessive linear proportions. The indices of refraction indicate that the most calcic feldspars form the central zone and the more sodic follow outward. The usual order of rate of weathering of the sodic and calcic feld-

FIG. 3.—Photomicrograph of a section from a pegmatite dike at Flat Rock Portage showing unusual development of zonal structure in sodium-calcium feldspar (crossed nicols; ×40).

spars does not hold in many of these crystals, as the second zone even with lower index of refraction often shows much more extensive alteration than the central zone. The alteration products are epidote and a mineral or mixture of minerals which has yellowish polarization colors and is believed to be epidote, kaolin, and zeolites. A peculiar influence of the pegmatitic intergrowth of the minerals is the crystallization of epidote in some of the zones

replacing the feldspar. This arrangement was seen where the path of an epidote crystal was cut across by that of the growing, zonally built feldspar. In a couple of cases a group of epidote crystals is crossed by feldspar, but the simultaneous extinction of all parts of the epidotes shows them to be parts of the same crystal and in one case particularly a portion of the epidote crystal has passed through the feldspar, forming one of the zones of the crystal. In these cases the epidote is undoubtedly primary, although considerable secondary epidote occurs from alteration of the feldspars.

An interesting example of a crushed feldspar is seen in this section where the crystal has been broken into slivers and the fragments surrounded by quartz. This must have been due to pressure, although the rock as a whole does not show evidence of excessive pressure beyond the undulatory extinction of some of the quartz grains.

In his description of the copper-bearing rocks of Lake Superior, Irving describes some sections from dikes of red rock in the Duluth gabbro which would indicate that they are probably similar to those dikes described above.[1]

These acid dikes appear to be differentiation phases of the Keweenawan diabases and gabbros because they occur, with one exception, in these rocks only, and, so far as observed, only in the larger masses and not in the thin sills which are too small to produce them by differentiation. This one exception is a dike 30 inches wide cutting quartzite and the overlying diabase near Ombabika Narrows.[2] This dike might be due to the rising of the liquid from some large diabase mass below through a fissure extending into the overlying rocks. There are no other bodies of acid rock in the region later in age than the Keweenawan diabases, and the pegmatitic and micropegmatitic textures suggest end phases of a magma. These dikes probably fill crevices in the diabase formed in the solidified exterior of a large mass, due to adjustment of pressures during processes of cooling, and the acid material rose from the still hot and more acid lower portions of the mass. The fact that these dikes are so much more basic on the whole than

[1] *U.S. Geol Survey, Monograph V*, 119–20.

[2] Coleman, *Bureau of Mines of Ontario*, XVII, 164.

the aplites of the Cobalt area may be due to the fact that the magma from which they separated was on the whole more basic. The ophitic texture of the diabases indicates a magma early saturated with calcium. The alkalies, being in small quantity, were mostly left over until the end of the crystallization period and then united with the remaining aluminium and silica to form potassium or sodium feldspars, while the small excess of silica occurring in a few places

FIG. 4.—Acid dikes filling columnar joint fractures in diabase.

went to form quartz. It is thus assumed that the magma became saturated with the more basic materials first, and the remaining acid materials, still liquid, were in some cases crowded toward the lower and central portion of the mass to escape into the fissures when opened, and form dikes.

In the case of the pegmatite dike in which the feldspar is largely calcic and occurs with the silica, it is probable that the excess of magnesium and iron caused the rocks to become saturated with

these elements, and the augite and olivine, separating out earlier, caused some of the calcium and aluminium to be left over to enter the dike.

It is interesting to note that in the Sudbury and Cobalt areas, where the Keweenawan rocks have suffered very great differentiation compared with that in the Lake Nipigon region, there are extensive ore bodies connected with them, while there is nothing but a little iron ore in the Nipigon region, and this occurs at the contact with sediments and may be leached from them.

While differentiation of magmas and thus the separation of the metals, as well as other elements, from the magmas, may be only one factor in the development of mineral veins as well as magmatic segregations, it seems probable that all data collected on this subject will show this is one of the important factors. Other things being equal, if the igneous rocks are the source of the metals, those magmas which show the greatest differentiation should be the most favorable for the production of ores, whether they supply metal-bearing solutions directly to the veins—a process quite conceivable in some cases—or whether they cause segregation of the metals so that they can readily be dissolved by meteoric waters in sufficient quantities to form ore deposits in veins.

GENERA OF MISSISSIPPIAN LOOP-BEARING BRACHIOPODA

STUART WELLER

Introduction

The correct specific determination of the loop-bearing brachiopod shells of the Mississippian faunas has always been attended with difficulty. This condition led the writer to undertake a critical study of a large amount of material, in order to determine, if possible, the true criteria for the determination of species. In this study the internal characters of the shell, as well as the external configuration, have been taken into consideration.

In the earlier literature all the shells of this type were included in the genus *Terebratula*, but since the appearance of Hall and Clarke's great work on the *Genera of Paleozoic Brachiopoda*,[1] it has been the usual custom to refer all of them to the genus *Dielasma*, although Girty has described one form as a member of the genus *Harttina*.[2] As a result of the present investigation, however, it has been found that forms which have been commonly included in a single genus, and in some instances, even, forms which have been referred to a single species, in reality represent several perfectly distinct generic types. The method used in the investigation is that which has been formerly used in the study of the Rhynchonelloid shells. Specimens have been ground from the posterior extremity and at short intervals the ground surface has been polished and a careful drawing made of the cross-section of the shell parts shown. From such a series of cross-sections of any shell it is easy to recognize the character and position of the internal lamellae, such as the median septum, the hinge-plate, the socket-plates, the bases of the crura, etc. In the course of the study it has been shown that the characters which can be considered as of

[1] *Paleontology of New York*, Vol. VIII, Parts 1 and 2.

[2] "*Harttina indianensis* Girty," *Proc. Nat. Mus.*, Vol. XXXIV, p. 293.

generic value in these shells are to be found in the rostral portion of the brachial valve. Six and possibly seven good generic groups have been recognized, and will be defined here.

Dielasma King

Description.—Shell terebratuliform. Pedicle valve with or without a median sinus, the beak strongly incurved, the foramen large and encroaching upon the umbonal portion of the valve; internally with well-developed dental lamellae. Brachial valve usually without mesial fold; internally the crural plates are separate from the dental socket-plates, they diverge from the apex of the valve with an elongate attachment to the inner surface of the valve, the free portion of the brachidium is short, with diverging

Fig. 1.—A series of fourteen cross-sections (×2½) of the rostral portion of the brachial valve of *Dielasma formosa* Hall.

descending lamellae; between the crural plates for the full length of their attachment to the inner surface of the valve, is a concave, transverse plate for muscular attachment, which joins the inner surface of the crural plates a little above their base; this plate rests against the inner surface of the valve along the median line for a portion or the whole of its length, or it may be free throughout; when attached along the median line a pair of slender cavities, triangular in cross-section, converge from the general cavity of the shell toward the beak, but when the transverse plate is not attached along its median line there is a single, broad and low cavity beneath the plate, extending toward the apex; anteriorly this plate extends to a greater or less distance beyond the attachment of the crural plates and is pointed, rounded, or emarginate in front; its surface is marked by concentric wrinkles parallel with

its anterior margin which are usually discontinuous along the median line.

Remarks.—The genus *Dielasma* was established by King with *Terebratula elongatus* Schl. as genotype, and although he defined the genus primarily upon the presence of prominent dental lamellae in the pedicle valve, and on the form of the loop, his illustrations of the internal casts of the species under the name *Epithyris elongata*[1] show that the crural plates are separate from the socket walls, one of the most essential features of *Dielasma* as here defined. Davidson[2] gives illustrations of the same species which exhibit all the essential generic characters of *Dielasma* most perfectly. The interpretation of the genus by Hall and Clarke[3] is identical with that here given, but those authors included certain species in the genus without sufficient investigation of their internal characters, which are fundamentally different; it has in fact been the usual custom among American workers, since the publication of Hall and Clarke's work, to refer all Mississippian terebratuloid shells to the genus *Dielasma*.

In specimens preserved in the condition of internal casts the generic characters of *Dielasma* are always very obvious, the position of the crural lamellae, separate from the socket-plates, being indicated by a pair of slits diverging from the beak of the brachial valve; when the transverse muscle-bearing plate is attached along its mesial line a second pair of diverging slits are present between those formed by the crural lamellae, and the finger-like casts of the slender cavities beneath the transverse plate are clearly shown, whether they are actually present or broken off. In specimens having the shell preserved the shell substance is frequently translucent enough to show the position of the internal lamellae as dark lines, in which case the genus can be recognized at once, and when the shell is opaque it is usually easy to determine the generic characters by the judicious use of a needle, without injuring the specimen as to its external form and characters upon which the various species are differentiated.

[1] *Monog. Perm. Foss. England*, Pl. 6, Figs. 37, 41 (1850).

[2] *Brit. Foss Brach.*, II, Permian, Pl. 1, Figs. 18, 20.

[3] *Pal. N.Y.*, VIII, Pt. 2, pp. 293–94.

Genotype.—*D. elongata* (Schl.). Other species, *D. formosa* (Hall), *D. shumardianum* (Miller), *D. ferrglenensis* Weller, *D. burlingtonensis* White.

GIRTYELLA n. gen.

Description.—Shell terebratuliform. The pedicle valve sinuate, with a large, subcircular or subovate, oblique foramen which encroaches upon the umbo; the brachial valve frequently sinuate and often with a slight median fold in the bottom of the sinus. Internally the dental lamellae are well developed in the pedicle valve. In the brachial valve the socket-plates are joined by a concave hinge-plate which is imperforate at the apex and is supported by a median septum; the inner sides of the dental sockets

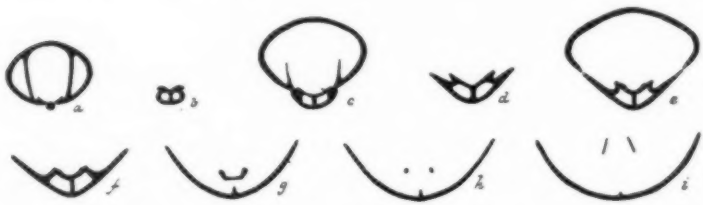

FIG. 2.—A series of nine cross-sections (×2½) of the rostral portion of the shell of *Girtyella indianensis* (Girty), three of which show both the pedicle and brachial valves, the others showing only the structure of the brachial valve.

retreat from the margins of the valve anteriorly beyond the point of articulation, and become the bases of the crura which are still joined by the concave hinge-plate and are also supported by lamellae resting against the inner surface of the lateral slopes of the valve. The brachidium short, its free portion apparently being like that of *Dielasma* and not reaching to the middle of the shell.

Remarks.—Members of this genus have commonly been included in the genus *Dielasma*, but they differ fundamentally from that genus in the presence of a median septum supporting the hinge-plate of the brachial valve, and in the origin of the bases of the crura from the socket-plates. In his description of the species which is selected as the genotype, Girty referred the form to the genus *Harttina* on account of the presence of a median septum in

the brachial valve, but the brachidium of *Harttina* is elongate, like that of *Cryptonella*, reaching nearly to the front of the shell, while that of *Girtyella* is short, like the brachidium of *Dielasma*.

Genotype.—*G. indianensis* (Girty). Other species, *G. turgida* (Hall), *G. brevilobata* (Swall.).

DIELASMOIDES n. gen.

Description.—Shell terebratuliform. Pedicle valve bisinuate toward the front in the genotype, the two depressions separated by a low, broadly rounded mesial elevation; the foramen large, oblique, encroaching wholly upon the umbonal region. Brachial valve with a slight mesial flattening or depression anteriorly in the genotype. Internally the dental lamellae are well developed in the pedicle valve; in the brachial valve the socket-plates are supported at their inner margins by a pair of lamellae which pass obliquely toward the floor of the valve to which they are joined

FIG. 3.—A series of seven cross-sections (×2½) of the rostral portion of the shell of *Dielasmoides bisinuata* n. sp., in the last three of which only the brachial valve is shown.

near the median line; between these lamellae, the outer walls of the valve and the socket-plates, are a pair of cavities narrowly triangular in cross-section which expand anteriorly and open out into the general cavity of the valve; the crura originate from the anterior extensions of the inner walls of the socket-plates. Form of the brachidium not known.

Remarks.—The characters of the rostral cavity of the brachial valve in this genus differ from those of *Dielasma* in the absence of any special crural lamellae distinct from the socket-plates. The two rostral cavities, narrowly triangular in cross-section, have a superficial resemblance in the two genera, but the narrow base of the triangle in this genus is formed by the socket-plate, while in *Dielasma* it is formed by the basal portion of the crural lamellae, and the special muscle-bearing plate between the bases of the crural lamellae of *Dielasma* is absent in this genus. This form is

perhaps to be compared with *Girtyella* as the genus most closely allied to it. If the concave hinge-plate of *Girtyella*, which is supported by a median septum, be depressed along its median line to such an extent that the concave plate itself rests directly upon the floor of the valve, the median septum being eliminated, then we would have essentially the characters shown in this genus. The bisinuate folding of the anterior portion of the pedicle valve may be a generic character, but this cannot be determined from the single species so far recognized.

Genotype.—*D. bisinuata* n. sp., St. Louis (?) oolite, Lewis County, Mo.

Cranaena Hall and Clarke

Description.—Shell terebratuliform. Pedicle valve with or without a median sinus and with well-developed dental lamellae

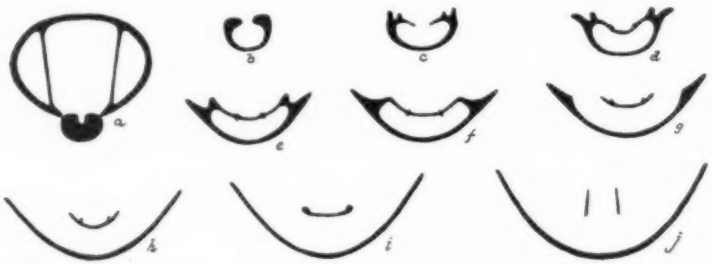

Fig. 4.—A series of ten cross-sections (×2½) of the rostral portion of the shell of *Cranaena iowensis* (Calvin), from all but the first of which the pedicle valve has been omitted.

Fig. 5.—A series of six cross-sections of the rostral portion of the brachial valve of *Cranaena* sp. undesc., residual chest, Springfield, Mo.

of moderate length internally, the foramen large, oblique, and encroaching upon the umbonal portion of the valve, the beak incurved. Brachial valve without median fold, even in those species with a well-defined sinus in the opposite valve, but sometimes with a slight mesial depression near the front margin; internally the well-developed socket-plates are connected transversely

by a concave hinge-plate which is perforated at the apex of the valve posteriorly; upon the inner or concave surface of the hinge-plate a pair of ridges originate at or near the anterior margin of the perforation and continue anteriorly across the plate, from the front of which they are produced into the crura. These crural ridges divide the hinge-plate into three equal divisions, or into two equal lateral divisions and a broader central one, and in some species the crural ridges are accompanied by similar ridgelike thickenings upon the opposite side of the hinge-plate. The brachidium short and *Dielasma*-like, not reaching to the middle of the valve.

Remarks.—This genus differs fundamentally from *Dielasma* in the origin of the crura from the thickened crural ridges of the hinge-plate, rather than from crural lamellae resting upon the inner surface of the valve, and in the absence of a special plate in the brachial valve for muscular attachment, the muscles being attached directly to the inner surface of the valve. From *Girtyella* the genus differs in the perforation of the hinge-plate, in the absence of a median septum in the brachial valve, and in the origin of the crura from crural ridges of the hinge-plate rather than from the anterior extension of the inner extremities of the socket-plates.

Genotype.—*C. romingeri* (Hall). Other species, *C. iowensis* (Calvin), *C.* n. sp., residual chert, Springfield, Mo.

HAMBURGIA n. gen.

Description.—Shell terebratuliform. Pedicle valve not sinuate in the genotype and only known species, the foramen large, oblique, encroaching upon the umbonal region; brachial valve without fold or sinus. Internally the pedicle valve is supplied with well-developed dental lamellae; the brachial valve with well-developed socket-plates which retreat from the lateral margins of the valve anteriorly beyond the articulation of the valves; they are connected transversely by a deeply concave hinge-plate which is separated from the inner surface of the valve by an exceedingly low and broad cavity; upon the inner or concave side of the hinge-plate a pair of ridges originate toward the apex and diverge

slightly while becoming stronger anteriorly, finally passing into the bases of the crura; shortly in front of the point of origin of the crural ridges on the hinge-plate the socket-plates are rapidly reduced in height and soon become obsolete, beyond which point the hinge-plate is not connected with the inner surface of the valve, but becomes a concave plate joining the bases of the crura and terminating anteriorly in a short distance. The complete form of the brachidium is not known, but it is probably short, not reaching the mid-length of the valve.

Remarks.—This genus is perhaps most closely allied to *Cranaena*, from which it differs in the extreme concavity of the hinge-plate, the cavity between it and the inner surface of the valve being reduced in height, and in the absence of the perforation of the

FIG. 6.—A series of nine cross-sections (×2½) of the rostral portion of the brachial valve of *Hamburgia typa*, n. sp.

hinge-plate at the apex, which is, perhaps, the most diagnostic character. The genus is totally distinct from *Dielasma*, in which the crural plates originate as ridges upon the inner surface of the valve instead of upon the concave surface of the hinge-plate. The concave, transverse plate between the bases of the crura is somewhat similar in the two genera except that it is not connected along its median line to the inner surface of the valve in *Hamburgia*, but in *Dielasma* the inner surface of this plate furnishes attachment for the adductor muscles, which is apparently not true in *Hamburgia*.

Genotype.—*H. typa*, n. sp., Hamburg oolitic limestone of Kinderhood age, Hamburg, Ill.

DIELASMELLA n. gen.

Description.—Shell terebratuliform, compressed. Pedicle valve with well-developed dental lamellae of moderate length. Brachial valve without median septum or true hinge-plate, the socket-

plates well developed, retreating from the lateral margins of the valve anteriorly and becoming differentiated into two portions, a basal portion which joins the inner surface of the valve and is directed obliquely inward, and a distal portion which is abruptly bent in a subgeniculate angle so as to be directed obliquely outward; the portion included in the angular bend of the two plates is produced anteriorly into the bases of the crura, and just before the crura become free a narrow transverse band joins their bases. The characters of the brachidium not completely determined, but it is believed to be of the short, *Dielasma*-like type. Shell structure finely punctate.

Remarks.—In the arrangement of the internal features of the apical portion of the brachial valve this genus is perhaps more closely allied to *Cranaena* than to any other of the generic types here recognized. It differs from *Cranaena* chiefly in the reduction

FIG. 7.—A series of six cross-sections (×2½) of the rostral portion of the brachial valve of *D. compressa* (Weller).

of the hinge-plate to a narrow, transverse band joining the crural bases, while in *Cranaena* it is elongate, with a comparatively small apical perforation, and with the crura originating as a pair of ribs diverging anteriorly from near the apex. The difference in shape, viz., the compressed shell and the erect beak of the pedicle valve, are other features which easily separate the members of this genus from all species of *Cranaena* which have been recognized.

Genotype.—*D. compressa* (Weller). Glen Park limestone.

ROWLEYELLA n. gen.

Description.—Shell terebratuliform, with the valves subequally convex. The beak of the pedicle valve perforated by a subcircular foramen which encroaches wholly upon the umbonal region, the delthyrium broadly triangular and wholly closed. Internally each valve is supplied with a strong median septum which, in the pedicle valve, reaches nearly to the center of the valve, that of the brachial valve being somewhat shorter.

Remarks.—The relationships of this genus cannot be certainly determined from the material available for study. The general contour of the shell at once suggests its affinity with the terebratuloid, loop-bearing shells, as also does the character of the foramen of the pedicle valve, and so far as it can be observed the delthyrium and its covering. The shell structure has not been certainly determined. Upon one example a punctate structure is slightly suggested, but that characteristic structure of the terebratuloids cannot be said to be demonstrated. The characteristic of these shells which is most foreign to the terebratuloids is the strongly developed mesial septum of the pedicle valve, which evidently supports a well-developed spondylium, and the presence of this character in association with a strong median septum in the brachial valve suggests the family Pentameridae, but it has not been determined that a cruralium accompanies this median septum of the brachial valve. This feature of a median septum in the pedicle valve has not been recognized heretofore among the loop-bearing terebratuloids, although there is perhaps no reason why it should not exist, but a median septum in the brachial valve occurs in at least one genus of these shells.

In any event the characters exhibited by these shells exclude them from any described genus among either the terebratuloids or the pentameroids. The presence of a pedicle median septum is sufficient to differentiate the genus from any other of terebratuloids, if indeed it be one of these shells, and the characters of the foramen and delthyrium differentiate it from any pentameroid. The shell perhaps agrees most closely in the sum of all the characters present with the spire-bearing *Camarophorella*, but there is no evidence, in the specimens observed, of the presence of a brachial platform associated with the median septum of that valve, as is true in *Camarophorella*.

Genotype.—*R. fabulites* (Rowley), Burlington white chert, Louisiana, Mo.

PHYSIOGRAPHIC STUDIES IN THE SAN JUAN DISTRICT OF COLORADO[1]

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The studies during the past field season were carried on near the southern and southwestern margin of the San Juan Mountains and over the adjoining plateau district. Investigations were planned for the purpose of working out the complete physiographic history of the district. The courses of the Pleistocene glaciers were indicated on the maps and the deposits left by those glaciers differentiated. In connection with these studies it was possible to differentiate the moraines of two distinct glacial epochs in each of the large canyons examined. Beyond the terminal moraines of each epoch and extending for many miles down stream, terrace remnants of valley trains were recognized. It was evident from the position of the younger glacial moraines and younger outwash valley trains that there had been a notable amount of valley deepening in hard rocks during the interglacial epoch. This suggests that the mountain area had been elevated by at least several hundred feet relative to sea-level during the Pleistocene period. The glacial features on the south slope of the range did not differ from glacial features which have been fully described by various writers who have become familiar with glacial phenomena in the high mountains of the West.

In examining the areas which rose above the upper limit of ice action on the south slopes of the mountains, certain gravel-strewn surfaces were found. The gravels were beautifully polished and of very resistant material. They were composed chiefly of quartzite, quartz, red jasper, flint, cherts, and greenstones. Much of the material was less than half an inch in diameter, but some of the pebbles ranged between one and two inches in their longer

[1] Published with the permission of the Director of the U.S. Geological Survey.

axes. The surfaces on which these gravels were found were along the crests between the great mountain canyons and on the tops of mesa-like hills near the base of the range. If the gravel-strewn surfaces were extended they would unite and form a plain of gently rolling topography. That plain would slope away from the core of the range, show a distinct warping at the base of the range, and pass off over the upland surfaces of neighboring plateaus. The nature and distribution of the gravels suggested that they were remnants of stream deposits in channels which formerly crossed the present inter-canyon ridges. They appeared to be the deposits of streams which flowed over low gradients and suggested further, by their distribution and the distribution and relations of the surfaces on which they were found, a deformed peneplain. In following this ancient erosion surface southward and southwestward over the plateau district it seemed that certain of the outlying mesa surfaces would correspond in age to this peneplain surface, and it was anticipated that on such outlying surfaces a mantle or scattering of still finer gravels might be found. But these mesa surfaces were found to carry a heavy mantle of bowlder-gravels, in which the larger masses ranged up to three and four feet in diameter. In these bowlder-gravel deposits certain special bowlders could be recognized which came from outcrops in the mountain areas, and it appeared that they must have been washed out and deposited as a portion of a great alluvial fan about the margin of the mountains. These bowlder-strewn surfaces were followed southward nearly fifty miles from the base of the range, and at that distance the larger bowlders seen ranged to at least three feet in diameter. The interpretation of this bowlder-gravel mantle and its relation to the erosion surfaces upon which it rests and the erosion surfaces in the mountains which seem to correspond in age to those underneath the bowlder-gravels is that at the close of the cycle of erosion during which the peneplain as described was developed, there was a general uplift in the district, which was emphasized in the San Juan dome. The headwaters of the streams in the uplifted dome were so rejuvenated that they carried together with sands and gravels many large bowlders to the base of the range and spread that material out as

alluvial fans over the neighboring plateaus. The streams which crossed the plateaus were first rejuvenated in their lower courses, and as rejuvenation worked upstream across the broad plateaus the growth of the great alluvial fans ceased and their dissection began. The high-level bowlder-gravels are, therefore, a deposit which marks the beginning of a new period of erosion in the mountains and a temporary period of alluviation about the base of the mountains. The bowlder-gravels are, therefore, not of exactly the same age, but a little younger than the small peneplain gravels of the mountain area.

Below the summit elevations in the mountains and in the neighboring plateaus there are other broad bowlder-capped mesa-like forms which appear to represent the base to which the streams worked when the peneplain was first deformed. The bowlder capping on these mesas is at places as much as thirty feet in thickness. The Florida and Fort Lewis mesas just south of the San Juan Mountains are typical of this bowlder-mesa stage in the dissection of the area. Another uplift associated with the more or less continuous growth of the mountains deformed the graded surfaces of the bowlder-mesa stage, again rejuvenated the streams, and opened another cycle of erosion. The surfaces to which the streams then worked are represented by broad, open valleys of late maturity or early old age in the softer rocks, and by canyons in the harder rocks. This cycle of erosion has been for convenience referred to as the Oxford stage, for there is an excellent development of the typical lowlands of this stage near the village of Oxford, a few miles southeast of Durango. It immediately preceded the first epoch of glaciation as recorded by the moraines and outwash deposits found on the south slope of the range. In the mountain-canyons the bowlder-mesa and Oxford stages are both represented by rock benches which in some instances carry stream alluvium.

These studies have opened certain large problems in the relationship of the mountains to the plateaus, and suggested a close correlation in the physiographic histories of the two provinces. Are the high-level bowlder-gravels resting on a true peneplain? Of what age is this peneplain? In the area examined during the

past season it is known to truncate Wasatch beds. Is it not, however, as late as late Miocene? Does it correspond in age to the great peneplains of the Grand Canyon district?[1] Are the high-level bowlder-gravels bordering the Front Range of the Rocky Mountains, the Big Horn Mountains,[2] the Livingston Range[3] of the same age as these about the San Juan Mountains? Do they rest on peneplain surfaces? Is the Blackfoot Peneplain of Montana described by Bailey Willis[4] of the same age as the one observed in this region? Are the Wyoming conglomerates about the base of the Uinta Mountains, placed in the Pliocene by the King Survey,[5] of the same origin and age as the high-level bowlder-gravels south of the San Juans? What is the relationship of certain bowlder deposits found near the summit and near the core of the San Juans, and certain ancient stream gravels which have been found by Stone, near the summit of the Front Range, to the bowlder-gravels about the bases of these ranges? Numerous other correlations in the Rocky Mountain areas and in the Pacific Coast mountains are suggested. Has there been with each period of mountain growth in the Cordilleran region of North America a rejuvenation of the streams which affected the headwaters long before it affected the middle courses of the rivers, and did these rejuvenated headwaters distribute the bowlder-gravels in each case on the neighboring plateaus? How far were such deposits carried and how were the larger bowlders transported? Numerous cases may be cited where bowlders ten to twelve feet in diameter have traveled at least twenty-five miles from their sources over surfaces of very low gradient. If such bowlders can travel twenty-five miles on gently sloping surfaces, is it not possible for them to travel much farther than that over low gradients? How are huge bowlders transported over nearly horizontal surfaces? How far have climatic changes affected the work of streams in the Rocky Mountain region? Are the reported glacial deposits in southeastern

[1] H. H. Robinson, *Am. Jour. Sci.*, 4th Series (1907), XXIV, 109–29.

[2] Salisbury and Blackwelder, *Jour. Geol.*, II (1903), 220–23.

[3] Bailey Willis, *Bull. Geol. Soc. Am.*, XIII (1902), 329–30.

[4] *Op. cit.*, 310.

[5] Hague and Emmons, *Rep. of 40th Parallel Survey* (1877), II, 64–65, 188–89 ff.

Utah,[1] in which there are granitic and gneissic bowlders one to five feet in diameter, the origin of which is at present unknown unless it be the San Juan Mountains, true glacial deposits or stream deposits? Could mountain glaciers from the San Juan Range have reached southwestward one hundred miles from the base of the range? Is there not some other explanation for the coarse bowlder deposits reported in that portion of the plateau district?[2] Has there been a continuous or periodic growth of the San Juan dome during late Tertiary and Quaternary times?[3] How are the great systems of fissures which cut the late Tertiary volcanics related in age to the recent deformative movements? Co-operative work by all who are engaged in field studies in the Rocky Mountains and plateau provinces should prove of great value in promoting the solution of these problems.

[1] D. D. Sterrett, *U.S. Geol. Survey, Mineral Resources* (1908), Pt. II, 825 (1909).

[2] W. M. Davis, *Proc. Am. Acad. Arts and Sci.*, XXXV (1900), 345–73.

[3] Cross and Spencer, *U.S. Geol. Survey 21st Ann. Rep.* (1900), Pt. II, 100.

THE VARIATIONS OF GLACIERS. XVI[1]

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The following is a summary of the *Fifteenth Annual Report* of the International Committee on Glaciers.[2]

REPORT OF GLACIERS FOR 1909

Swiss Alps.—Of the ninety glaciers measured in 1909, only two have been advancing for three successive years, the Scex-rouge and the lower Grindelwald Glacier; the latter has advanced 59 meters in two years. Nine other glaciers have advanced slightly during the last year but it is not certain that they are in a stage of advance. A general retreat is dominant in the Swiss Alps.[3]

Eastern Alps.—Thirty-nine glaciers were measured, and the retreat is general, although in many cases it is slow. The Langtaler Glacier and the Grosselendkees seem to be stationary, and the Mitterkarferner has made a small advance.[4]

Italian Alps.—The retreat, which has been general for some years, seems to be continuing without change.[5]

French Alps.—Observations on the snow-fall and the variation in the length of glaciers have continued, and maps of some glaciers are being made on a scale of 1 : 10,000. In the Mont Blanc range the retreat is nearly general, though slight; the Glacier des Bossons has advanced a little more than one meter. The ends of the glaciers have in general diminished in thickness with a corresponding diminution in the velocity of flow. In the Tarentaise and Maurienne the retreat is also general, but feeble. In the Dauphiné we find that the snow-fall has been distinctly heavier since 1906 with the result that the glaciers on the northern side of the Pelvoux massif have grown thicker and are beginning to advance; and the

[1] The earlier reports appeared in the *Journal of Geology*, Vols. III–XIX.

[2] *Zeitschrift für Gletscherkunde* (1911), V, 177–202.

[3] Report of Professor Forel and M. Muret.

[4] Report of Professor Brückner.

[5] Report of Professor Marinelli.

whole appearance of the reservoirs indicates that the advance in this region will become general. In the southern part of the same massif, although the increase in the snow-fall is also marked, the retreat of the glaciers continues. In the Pyrenees the snow-fall has been heavy since 1906 and the small glaciers show a marked tendency to increase in size.[1]

Swedish Alps.—A number of glaciers have been measured and the changes resulting during a variable number of years up to 1909 indicate a slight increase in general, though a few of the glaciers are apparently stationary and one or two slightly retreating.[2]

Norwegian Alps.—The difference in the behavior of the glaciers of Jotunheim, in the interior of Norway, and those of Folgefon and Jostedalsbrä, near the coast, which was commented on in the last report, continues. The glaciers near the coast are generally advancing, whereas those in the interior are generally retreating.[3]

Russia.—The greater part of the glaciers observed in the Caucasus between 1899 and 1907 have retreated. A few have remained stationary and only two have made an advance. A number of glaciers in the Altai and Muss-tau mountains, in Siberia, have been visited but no careful measurements made.[4]

REPORT ON THE GLACIERS IN THE UNITED STATES FOR 1910[5]

There are a number of small glaciers in Colorado which, on the whole, show a tendency to become smaller, but their variations from year to year are extremely slight.[6]

The Hallett Glacier shows no measurable change since 1909 (Mills).

The Carbon Glacier on the northern side of Mt. Rainier is in marked recession (Matthes).

The United States Geological Survey has been continuing its

[1] Report of M. Rabot.

[2] Report of Professor Hamburg.

[3] Report of M. Oyen.

[4] Report of Colonel Schokalsky.

[5] A synopsis of this report will appear in the *Sixteenth Annual Report* of the International Committee. The report on the glaciers of the United States for the year 1909 was given in this Journal (XIX, 83–89).

[6] All available information regarding these glaciers has been collected by Judge Junius Henderson, "Extinct and Existing Glaciers of Colorado," *University of Colorado Studies* (1910), VIII, 33–76.

explorations and surveys of Alaska, and several glacier regions have been mapped. A number of glaciers north of Juneau are in rapid recession. The glaciers in the neighborhood and north of the headwaters of the Copper River (in the neighborhood of latitude $63\frac{1}{2}^\circ$ N and longitude 145° W) seem to be retreating slowly (Brooks).

Fresh moraine, extending for nearly two miles at the end of Nabesna Glacier, shows that it is retreating rather rapidly. The Chisana Glacier, 15 miles to the east, has a very clean end; a comparison of photographs taken in 1899 and 1908 shows surprisingly little change in the aspect of the glacier, though at one place a slight recession has taken place. Frederika Glacier, entering White River valley from the north, when seen by Dr. C. W. Hayes in 1891 ended "in a nearly vertical ice cliff . . . . about 250 feet high. At the foot of the cliff there is a small accumulation of gravel and ice fragments apparently being pushed along by the advancing mass."[1] In 1909 Mr. Stephen R. Capps says "its surface is remarkably smooth and slopes down evenly to a thin edge in front." The Frederika Glacier has evidently changed from an advancing to a retreating glacier in the interval. Exactly opposite Frederika Glacier another glacier, in retreat in 1891, is now advancing.[2]

Such spasmodic cases are probably produced by sudden accession of material due to avalanches or land slides, rather than to simple variations in snow-fall or temperature.

The Ruth Glacier, rising on Mt. McKinley and extending many miles to the east, is slowly diminishing in size (Rusk).

Professor U. S. Grant and Mr. D. F. Higgins have published a general map of Prince William Sound, showing the location of all the glaciers, on a scale of 4 inches to the mile.[3] They have also published descriptions, pictures, and detailed maps of the ends of several of these glaciers.[4] The last observations were made in

[1] "Expedition through the Yukon District," *Nat. Geog. Mag.* (1892), IV, 153.

[2] "Glaciation on the North Side of the Wrangell Mountains, Alaska," *Jour. Geol.* (1910), XVIII, 56.

[3] "Reconnaissance of the Geology and Mineral Resources of Prince William Sound, Alaska," *U.S. Geological Survey, Bulletin No. 443*, Washington, 1910.

[4] "Glaciers of Prince William Sound and the Southern Part of the Kenai Peninsula, Alaska," *Bull. Amer. Geog. Soc.* (1910), XLII, 721–33.

the summer of 1909 and we note that the Shoup Glacier was practically stationary and was fully as large then as it had been for several decades. The Columbia Glacier was found, at its eastern edge, about 500 feet in advance of its position of 1899, and this advance seems to have taken place principally since the summer of 1908. Professor Grant found indications that the glacier was well in advance some fifty years ago and before that date was considerably smaller. The Meares Glacier seems to be a little in advance of its position of 1905, and the general condition of the vegetation in the immediate neighborhood indicated that the glacier in 1909 was probably as far forward as it has been during the last one hundred years or more.

Professor Lawrence Martin conducted another expedition for the National Geographic Society in 1910 to study the Alaskan glaciers. He sends me the following notes:

Fairweather Range.—La Perouse Glacier advanced approximately a quarter mile between September 4, 1909, and June 10, 1910, and was destroying forest on the latter date, as it had previously done in September, 1895.

Yakutat Bay.—Nunatak Glacier advanced 700 to 1,000 feet between July 6, 1909, and June 17, 1910, after retreating steadily at least 2½ miles from 1890 to 1909. Hubbard Glacier did not continue to advance as rapidly as seemed possibly would be the case in 1909, parts of the front advancing 600 feet between 1909 and 1910 while other parts retreated 500 to 1,000 feet. In 1910 Lucia Glacier had probably nearly ceased the great advance which was in progress in July, 1909. Nunatak Glacier is the ninth ice tongue in the Yakutat Bay region to advance since 1899, following a long period of continuous retreat or stagnation. In each case listed below the advance is thought to be the result of great accessions of snow and ice by avalanches during the earthquakes of September, 1899.

Glacier	Date of Advance	Length of Glacier
Galiano*	After 1895 and before 1905	2 or 3 miles
Unnamed Glacier	1901	3 or 4 miles
Haenke	1905–6	6 or 7 miles
Atrevida	1905–6	8 miles
Variegated	1905–6	10 miles
Marvine	1905–6	10 miles†
Hidden	1906 or 1907	16 or 17 miles
Lucia	1909	17 or 18 miles
Nunatak	1910	20 miles

* Between Haenke and Hubbard glaciers.

† Excluding expanded lobe in Malaspina.

Prince William Sound.—Columbia Glacier advanced 600 feet between August 24, 1909, and July 4, 1910, and at least 132 feet more between the latter date and September 5, 1910. In College Fiord the Harvard, Yale, Radcliffe, Smith, Bryn Mawr, Vassar, Wellesley, and Barnard glaciers were advancing much more actively in 1910 than in 1909, and were destroying forest at their borders, as were the Meares Glacier in Unakwik Inlet, the Harriman, Baker, Roaring, and Cataract glaciers in Harriman Fiord, and the Blackstone Glacier in Blackstone Bay. Harvard glacier had advanced 100 to 150 feet, Yale 750 feet, and Harriman 300 feet between 1899 and 1910. Barry and Surprise glaciers in Harriman Fiord retreated $2\frac{1}{2}$ and $1\frac{1}{4}$ miles respectively from 1899 to 1910, different parts of the Barry retreating 500 to 1,600 feet of this distance between 1909 and 1910. Valdez and Shoup glaciers in eastern Prince William Sound and Nellie Juan Glacier in Port Nellie Juan remained unchanged from 1908 to 1910, as did Chenega, Princeton, and Tiger glaciers in Icy Bay, where there was a six or seven mile retreat between 1787 and 1908, most of it later than 1898. Portage Glacier in Passage Canal had a great advance between 1794 and 1880, filling a pass from Prince William Sound to Cook Inlet to a height of over 1,000 feet, where there was previously a low canoe portage and no glacier.

Copper River.—Miles Glacier retreated about 1,700 feet from 1900 to 1906 and readvanced 1,800 feet from 1906 to 1910. Grinnell Glacier advanced slightly between 1909 and 1910. Different parts of the front of Childs Glacier advanced 920 to 1,225 feet between 1909 and June, 1910, in midglacier, where the front is undercut by Copper River. On the north bank of the river where the margin of the glacier ends on the land and was stagnant in 1909, it advanced 1,500 to 1,600 feet up to June 10, 1910, and 204 feet more up to October 5, 1910. The glacier front developed lobes so that some parts advanced faster than others. The rates per day through the summer of 1910 were as follows:

Dates	Days	Advance in Meters		Rate per Day in Feet	
		Fastest	Average	Fastest	Average
June 10 to July 29	49	124	116	2.5	2.37
July 29 to Aug. 6	8	26	23	3.25	2.87
Aug. 6 to Aug. 11	5	41	8	8.2	1.60
Aug. 11 to Aug. 17	6	27	4	4.5	0.66
Aug. 17 to Aug. 29	12	42	19	3.5	1.58
Aug. 29 to Sept. 19	21	37	27	1.76	1.28
Sept. 19 to Oct. 5	17	13	$7\frac{1}{2}$	0.7	0.44

In midglacier there was a relative retreat of the advancing ice front from June to September, while the north border continued to advance strongly, as shown above. This retreat was due to undercuttings during the summer

rise of the river and was followed by a strong advance in late September and early October when the level of the river fell and its undercutting power was weakened. This oscillation is shown in the accompanying table.

Dates	Variation of Glacier	Stage of River
1909 to June 10, 1910.....	Advance, 920–1,225 ft.	Fall, 14 ft., May 6 to June 10
June 10 to Aug. 11.....	Retreat, 450 ft.	Rise, 6 ft.
Aug. 11 to Aug. 17.....	Retreat, 65 ft.	Level, about stationary
Aug. 17 to ———.....	Retreat continued.....	Rise, $1\frac{7}{10}$ ft.
——— to Oct. 5.....	Advance, 390 ft., plus unknown retreat above	Fall, 9 ft.

As this advance of Childs Glacier seriously threatened a $1,400,000 steel railway bridge which in October, 1910, was only 1,575 feet from the north margin of the glacier, the behavior of Childs Glacier during the winter of 1910–11, when Copper River is low and weak, will be of much interest. The diminution of movement on the north bank suggests, however, that the advance is practically over. The advance of Grinnell Glacier is also of interest, for this ice tongue occupies a strategic position with reference to the railway, which traverses its stagnant outer portion. In this portion, however, there was no disturbance in 1910, the advance affecting another part of the glacier. The Allen Glacier, whose stagnant outer portion is traversed for $5\frac{1}{2}$ miles by this railway, remained unchanged from 1909 to 1910.

It appears, therefore, that the glaciers about Prince William Sound give some indication of a general, but not very large, advance.

CORRECTION.—In the Report on the Glaciers of the United States for 1908 (*Journal of Geology*, XVII, 671), the name "Matamaka Glacier" should have been "Matanuska Glacier."

The regular meeting of the International Committee on Glaciers took place in Stockholm on the 20th of August, 1910, in connection with the Eleventh International Geological Congress.[1] The retiring president, Professor Edouard Brückner, presented the report of the Committee to the Congress.

He called attention to the origin of the Committee, which was first appointed by the Sixth International Geological Congress in 1894, and has been collecting information regarding the variations of glaciers ever since; and emphasized the importance of the work

[1] "La Commission internationale des Glaciers au Congrès géologique international, Stockholm, août, 1910." *Zeitschrift für Gletscherkunde* (1911), V, pp. 161–76.

of Professor Finsterwalder, who, as retiring president in 1903, laid down the fundamentals of a mathematical theory of glacier variations. He then reviewed the information collected regarding the variations of glaciers. In the Alps the retreat of the glaciers continues steadily, although a few glaciers of the Oetztal and some others have made small temporary advances. The retreat has lasted for several decades. A graphic representation of the variations of 26 glaciers in the Swiss Alps, including the Mont Blanc group, shows that, for the greater number of them, the retreat has lasted since the beginning of the nineteenth century, and that the advance which occurred about 1850 was but an episode in the general retreat. Since that time the retreat has been still more marked. In the Scandinavian Alps the variations have been somewhat different; in this region an advance occurred in the beginning of the twentieth century. It began in the Jostedalsbrä and the Folgefon and progressed toward the north; but the advance was confined to the coast region and the glaciers in the mountains of central Scandinavia did not participate in it. This advance must also be looked upon as an unimportant event in the general retreat. The glaciers of the Caucasus, of the Tyan-Shan, the Altai, the Highlands of Pamir, and the Himalaya are in retreat, though here also special cases of advance have been noted. Among the glaciers of the United States and Canada the retreat is general and this is true to a still more marked extent in Alaska. Between 1892 and 1907, the retreat of the glaciers has increased the area of Glacier Bay by 19 square miles. Of great interest are the sudden remarkable advances of the glaciers of Yakutat Bay, which Professor R. S. Tarr has described and imputed to the great increase in snow-supply due to avalanches incited by the earthquakes of 1899. Professor Hauthal has described the rapid advance of the Bismarck Glacier, in South America, since the end of the last century.

Professor Kilian described the variations of glaciers in France. The importance of the water from glacial streams has led the Minister of Agriculture to give material aid to the observations of glaciers.

Professor Dr. F. W. Svenonius spoke of the difficulty of making

observations among the Swedish glaciers on account of their distance and inaccessibility, but nevertheless the Swedish Geological Survey has published a collection of six essays by the leading Swedish glacialists which give an excellent account of what is known of these glaciers.[1]

[1] Dr. Axel Hamberg has been elected an ordinary member of the Committee to represent Sweden, succeeding Dr. F. W. Svenonius, who has retired and been elected a corresponding member. Professor R. S. Tarr has also been elected a corresponding member. Two corresponding members, Mr. W. S. Vaux, Jr., and Professor E. Hagenbach-Bischoff, have died since the 1906 meeting of the Committee. The following officers were elected to serve until the next meeting of the International Congress of Geologists: Honorary President, Prince Roland Bonaparte of Paris; Active President, M. Charles Rabot of Paris; Secretary, M. Ernest Muret of Lausanne.

Petrological Abstracts and Reviews

Edited by ALBERT JOHANNSEN

ARSCHINOW, WLADIMIR. "Ueber die Verwendung einer Glashalbkugel zu quantitativen optischen Untersuchungen am Polarisationsmikroskope," *Zeitschr. Kryst.*, XLVIII (1910), 225–29. Fig. 1.

A simple apparatus for making quantitative measurements by tilting a thin section under the microscope. The author claims to be able to make measurements with as great a degree of accuracy as may be made with Fedorow's or Klein's Universaltisch.

The instrument consists of a glass hemisphere, 50–60 mm. in diameter, which is centered upon the stage of the microscope and rotated by hand. The section is fastened to the flat side of the hemisphere with cedar oil or glycerin, and with the cover-glass down. The determination of planes of extinction and so on are made as with the Fedorow Universaltisch, and the angle of rotation is measured by means of two graduated metal strips, attached 90° apart, to a movable ring around the equator of the glass hemisphere, and themselves capable of being moved on pivots. By raising the tube of the microscope above these rings, the angles at which they cross may be read, and this determines the amount of rotation of the glass hemisphere. For certain measurements a small glass hemisphere, 8–15 mm. in diameter, is attached to the upper surface of the slide.

ALBERT JOHANNSEN

BASTIN, EDSON S. "Geology of the Pegmatites and Associated Rocks of Maine," *Bull. U.S. Geol. Survey No. 445*, Washington, 1911. Pp. 152, pl. 18, figs. 8, map 1.

In this bulletin on the pegmatites of Maine, Doctor Bastin has given not only local descriptions but has made an important contribution to the general literature of the pegmatites as well. The work is divided, practically, into three parts: a general discussion of pegmatites

and in particular those of Maine, local descriptions by counties, and descriptions of the economically important minerals.

Granite-pegmatites are defined here as differing but little from the granites of the state in mineral composition, but are characterized, not necessarily by coarse, but by extreme irregularity of grain. They occur in dikes or sill-like masses, generally of sheet-like form and sometimes of considerable size. The contact with the country rock is generally sharp, indicating very little assimilation by the pegmatite even where it is of batholithic dimensions. Contact metamorphism around the pegmatites is no greater than that near granite contacts, and indicates, according to the writer, that the amount of mineralizers present was but little greater than in the latter rocks; less than ten times as great, probably. Genetically the pegmatites are related to the associated granites and are probably contemporaneous with them. Where particularly abundant, they form, apparently, the roofs above granite batholiths. An examination of the quartz grains indicates, in the coarser varieties, that the crystallization began slightly above 575° C. and ended at a lower temperature. The finer-grained varieties may have crystallized entirely above 575°.

Among the minerals of economic importance found in the Maine pegmatites are the feldspars, orthoclase and microcline rose and smoky quartz, amethyst, muscovite, tourmaline, beryl of various colors, and topaz. The occurrences, compositions, properties, and uses of these minerals are discussed.

ALBERT JOHANNSEN

COUYAT, J. "Les roches sodiques du désert arabique," *Comptes Rendus de l'Académie des Sciences*, CLI (1910), 1138–41.

In a region east of the Nile, near longitude 34° 18′ E., latitude 24° 40′ N., there are dikes and stocks of nepheline syenite with much variation in texture, also tinguaite and sölvsbergite. Four analyses of the syenite show SiO_2 60.1 to 56.5 per cent; Na_2O 9.0 to 10.6 per cent; K_2O 4.5 to 5.2 per cent; Fe_2O_3, FeO 3.2 to 6.1 per cent; very low MgO and CaO. In the quantitative classification the rocks are miaskoses and laurdaloses.

The syenites are related to volcanic eruptives of Cretaceous age and posterior to a series of trachytes, andesites, and basalts.

F. C. CALKINS

DUPARC, L., AND PAMPHIL, G. "Sur l'issite, une nouvelle roche filonienne dans la dunite," *Comptes Rendus de l'Académie des Sciences*, CLI (1910), 1136–38.

The rocks described form dikes in massive dunites of the platinum deposits in the basin of the river Iss. They consist mainly of hornblende, with subordinate pyroxene, labradorite in some cases, magnetite, and apatite. Five analyses are given. SiO_2 ranges approximately from 33 to 47 per cent; Fe_2O_3 from 3 to 9 per cent; FeO from 14 to 9 per cent; CaO from 16 to 11 per cent; MgO from 10 to 7 per cent; total alkalies 2 to 3 per cent. In the quantitative classification, the rocks fall in auvergnose and three unnamed subrangs.

F. C. CALKINS

DUPARC, L., AND WUNDER, M. "Sur les Serpentines du Krebet-Salatim (Oural du Nord)," *Comptes Rendus de l'Académie des Sciences*, CLII (1911), 883–85.

Describes dunites and harzburgites more or less completely altered to antigorite and bastite. Five analyses of these rocks and one of the inclosed calcareous hornfels are given.

F. C. CALKINS

GRANDJEAN, F. "Sur un mesure du laminage des sédiments (calcaires et schistes) par celui de leurs cristaux clastiques de tourmaline," *Comptes Rendus de l'Académie des Sciences*, CLI (1910), 907–9.

The author finds tourmaline an unfailing constituent of shales and limestones. The crystals of this mineral in deformed rocks show a middle portion normal in color and apparently undeformed, and ragged terminal portions of paler hue. The terminal zones are considered due to elongation of the tourmaline, and their average length (about 30 measurements is ordinarily sufficient) gives a co-efficient of deformation for the rock.

F. C. CALKINS

GROTH-JACKSON. *The Optical Properties of Crystals*. New York: John Wiley & Sons, 1910. Pp. xiv+309, figs. 121, colored plates 2.

In spite of a number of good books on optical crystallography which have appeared within the past few years, no work has quite taken the

place of Groth's classical *Physikalische Krystallographie*, and it is with great pleasure that this translation of certain parts is welcomed. The only criticism that can be made is that Professor Jackson did not translate the entire work.

The translation, in general, follows the form of the original and includes all of the "Optical Properties" in Part I, with additions, here and there, from the parts in the original devoted to systematic descriptions of crystals and methods of crystal investigation. The translation seems to be good, although, in places, the sentences, closely following the German, are rather long. A slight error is introduced, on p. 15, where the number of vibrations per second of red and violet light are spoken of, by the translation of the German billion (10^{12}) as billion (10^{9}).

The book is well gotten up, and the line drawings, apparently from wax plates, are sharp and clear.

ALBERT JOHANNSEN

HOWE, J. ALLEN. *The Geology of Building Stones.* New York: Longmans, Green & Co.; London: Edward Arnold, 1910. 12mo, pp. viii+455, pl. 8, maps 7, figs. 31.

This work, the fourth of Arnold's Geological Series, under the general editorship of Dr. J. E. Marr, apparently is intended primarily for architects. It treats of the rock-forming minerals and the rocks in non-technical language and gives the principal properties of each. The decay of building stone is discussed, and methods of testing are described. The author says, "There is no help: sooner or later, in the course of practice, the architect or engineer will have the need of some geological knowledge forced upon him." If the little knowledge is not a dangerous thing, this book may serve a useful purpose.

ALBERT JOHANNSEN

LACROIX, A. "Le cortège filonien des péridotites de la Nouvelle Calédonie," *Comptes Rendus de l'Académie des Sciences*, CLII (1911), 816–22.

The peridotites of Nouvelle Calédonie are cut by narrow dikes forming a gabbroic and a dioritic series. In both, gradations can be traced between a leucocratic extreme (anorthosite) and a melanocratic extreme, (pyroxenite or hornblendite). Nine analyses are given which prove that six of the rocks fall into previously unnamed subdivisions of the

quantitative classification. These are: Ouenose (III. 5. 5. 4–5); Caledonose (I. 5. 5. 4–5); Thiose (IV. 1[2]. 1[2]. 2); Naketose (IV. 2[3]. 1[3]. 2); Koghose (III. 4. 4. 4–5).

In the gabbroic series, SiO_2, Al_2O_3, and CaO increase together, while FeO and MgO decrease. Because of the basicity of the feldspars the most feldspathic phase is the poorest in SiO_2. In the dioritic series, the proportion of lime is nearly constant, silica varies irregularly, Al_2O_3 and alkalies increase with the feldspar content.

There are also dikes composed almost wholly of magnesiochromite; these locally contain chrome-bearing diopside and bronzite, and are associated with anorthosites.

F. C. CALKINS

LEISS, C. "Neues Mikroskop Modell VI*b* für krystallographische und petrographische Studien," *Zeitschr. Kryst.*, XLVIII (1910), 240–42. Fig. 1.

A large microscope similar in construction to the Hirschwald microscope (Fuess VI*a*). It differs, however, in having an Abbe condenser and Ahrens polarizer, and a large, flat micrometer stage. Like the VI*a* microscope, the upper and lower nicols can be rotated simultaneously. This does away with the cap nicol and permits the use of a large tube, giving an extra large field.

ALBERT JOHANNSEN

SKEATS, ERNEST W. "The Volcanic Rocks of Victoria," *Australian Association for the Advancement of Science*, 1909, 173–235. Pl. 4, numerous analyses.

This paper was read as the Presidential Address, Section C, of the Australian Association for the Advancement of Science. It contains a summary of the present knowledge of the Victorian volcanic rocks and has appended a bibliography of 268 items, dealing wholly, or in part, with these rocks. The geographical distribution is shown on a map and the geological range was determined to be from Basal Ordovician (?) to recent. Petrographically the rocks are rhyolites, dacites, basalts, quartz porphyries, granite porphyries, diabases, serpentines, quartz keratophyres, melaphyres, sölvsbergites, limburgites, and the new rocks anorthoclase trachyte, anorthoclase-olivine trachyte, olivine-anorthoclase basalt, olivine-anorthoclase andesite, and macedonite. Petrographical descriptions, not as complete as might be desired, espe-

cially those dealing with new types, are given, and the geographical and geological relations are shown. The new rock terms proposed are:

Anorthoclase trachyte.—This type was previously described by Professor Gregory as trachyphonolite. As described by Skeats, in a corrected copy of his paper, it is "a dark-greenish rock. Large phenocrysts of anorthoclase are numerous. The ground mass has sometimes a fluidal arrangement of laths of anorthoclase, in other cases the crystals are stouter and the structure orthophyric. Small crystals of aegirine are scattered through the rock, a little green glass, a few sections of nosean, ilmenite, and occasionally apatite are also present." From the description it does not appear that any other feldspar occurs, although the statement, in another place, that "anorthoclase is the dominant felspar," suggests that another is present.

Anorthoclase-olivine trachyte.—Spoken of as "more basic than the rock just described." It resembles the former rock but contains, in addition, more or less olivine.

Olivine-anorthoclase basalt.—"A still less acid type. . . . . It differs mainly from the last type in the greater abundance of olivine and less frequent anorthoclase." In the opinion of the reviewer this description would hardly justify the use of the term basalt.

Macedonite is a non-porphyritic, basaltic-looking rock and in the annotated copy is said to "consist largely of minute felspars, a colourless to green interstitial mineral, either glass or chlorite, serpentine or chlorite pseudomorphs after olivine, some light-brown biotite and purplish, fibrous apatite prisms. Octahedra of perofskite occur, some of which are opaque, others of a dark grayish-green colour. The exact relations of this rock are difficult to determine. Chemically it is in some respects intermediate between the tephrites and the orthoclase basalts, but mineralogically it is quite distinct. Its nearest relations are with the mugearites, from which it differs in the ratio of soda to potash and in the small amount of olivine present." The writer does not say what kind of feldspar is present, but if the analysis is computed in the Quantitative System of C.I.P.W., the norm shows orthoclase, 20.02 per cent, albite, 29.87 per cent, and anorthite, 18.63 per cent. As computed by the reviewer the rock is a Shoshonose.

Olivine-anorthoclase andesite.—This is a porphyritic, subsiliceous andesite. It contains lath-shaped plagioclase and granular or ophitic augite, magnetite, and olivine as its normal constituents. Corroded phenocrysts of anorthoclase occur and connect this type with the alkali rocks.

While exact and detailed descriptions may seem tedious in an address, it would be desirable in printed descriptions of new types of rocks that they be made as complete as possible and that the relative amounts of the different constituents be stated. For such rocks, clear-cut definitions should be given.

The paper is a well-written summary of what is known of the volcanic rocks of Victoria, and one is always thankful for contributions containing careful analyses and complete bibliographies.

ALBERT JOHANNSEN

WATSON, THOMAS L. "Intermediate (Quartz Monzonitic) Character of the Central and Southern Appalachian Granites," *Bull. Phil. Soc., Univ. Va.*, I (1910), 1–39.

By comparing the analyses of granites from different parts of the Appalachian region, the author finds that they are, in general, of monzonitic character, the soda being molecularly equal to or greater than potash. Comparing the western granites with the Appalachian rocks, he finds that "the eastern type shows stronger granite affinities and the western type stronger quartz diorite affinities." In general the granites of the eastern region are of similar composition, containing acid oligoclase and some albite in addition to potash feldspar; the ratio averaging 1.88 to 1. All of the granites, from Alabama to New England, as well as the subsilicic gabbros, diabases, pyroxenites, and peridotites, "have been derived from a common parent body of magma intruded, in most cases, at different times," says the writer. The age of the massive granite is stated to be early or later Paleozoic, while the granite-gneisses (gneissoid-granites) are pre-Cambrian.

Numerous analyses, all of them partial, are given.

ALBERT JOHANNSEN

Reviews

The Coming of Evolution: the Story of a Great Revolution. By John W. Judd. London and Edinburgh: The Cambridge University Press, 1910. Pp. 171.

The numerous addresses which were delivered in various parts of the world in connection with the recent Darwin Centenary seem to have had for their common burden the revivification of all science by the revolution which Darwin introduced in the biological field. Seldom has it been pointed out, and never before in so convincing a manner, that the acceptance of evolution for the organic world was a direct outgrowth of its demonstration in the field of geological science. It was the publication by Sir Charles Lyell in 1830–33 of his *Principles of Geology*, giving currency to continuity or uniformitarianism in the realm of inorganic nature, that laid the foundations of modern geology and paved the way for modern biology as well. Darwin was first a geologist, and his great debt to Lyell he was ever ready to acknowledge. Says Professor Judd: "Were I to assert that if the *Principles of Geology* had not been written, we should never have had the *Origin of Species*, I think I should not be going too far; at all events, I can safely assert, from several conversations I had with Darwin, that he would have most unhesitatingly agreed in that opinion."

Huxley has given his verdict that "consistent uniformitarianism postulates evolution as much in the organic as in the inorganic world." In dedicating the second edition of his favorite work, the *Narrative of the Voyage of the Beagle*, Darwin wrote: "To Charles Lyell, Esq., F.R.S., this second edition is dedicated with grateful pleasure, as an acknowledgment that the chief part of whatever scientific merit this journal and the other works of the author may possess, has been derived from studying the well-known admirable *Principles of Geology*." To Leonard Horner he wrote: "I always feel as if my books came half out of Lyell's brain." In the *Origin of Species* Darwin refers to "Lyell's grand work on the *Principles of Geology*, which the future historian will recognize as having produced a revolution in Natural Science."

The *Coming of Evolution*, first in the geological and later in the biological field, has fortunately now been told by a veteran geologist

and one who enjoyed the friendship of all the great leaders in the movement—Huxley, Hooker, Scrope, Wallace, Lyell, and Darwin. Of those who were on terms of affectionate intimacy with both Charles Lyell and Charles Darwin, Professor Judd is perhaps the unique survivor. It is this intimate personal relationship to the chief actors in the great drama, combined with a peculiarly simple and graceful style of writing, which makes the fascination of this little book. At every turn of the page the reader is surprised by the reference to some remark of Lyell, Darwin, or Huxley, which sheds a flood of light upon the psychology of the whole movement.

The great success of the *Principles of Geology* seems in some measure to have been due to Lyell's study of the causes of failure of the *Theory of the Earth* by the illustrious Hutton, whose death occurred the year Lyell was born. On the basis of his extended observations, Hutton as early as 1785 wrote the oft-quoted, "I can see no evidence of a beginning, and no prospect of an end," a blunt statement which antagonized the church, then especially active in hunting heresy. Furthermore, his work was written in a heavy and cumbrous style. Profiting by this example, Lyell schooled himself in graceful, accurate, and forceful expression, and at some pains and with favoring fortune was able to avoid a clash with the established church. In no small measure this was due to an extremely favorable notice of his *Principles* in the *Quarterly Review*, then the champion of orthodoxy. With the geologists of the official Geological Survey, Lyell was less fortunate, and in spite of the general popularity of his epoch-making ideas, they were bitterly fought by the official class of geologists and only slowly won support in this field. Professor Judd's fascinating story of the coming of evolution should find a wide circle of readers, especially among students of natural science.

W. H. H.

North American Index Fossils: Invertebrates. By Amadeus W. Grabau and Hervey Woodburn Shimer. Vols. I and II. New York: A. G. Seiler & Co., 1909 and 1910.

With the rapid accumulation of special literature in the field of systematic paleontology, and the growing inaccessibility of many of the older works except to those having access to large libraries, it is ever becoming more and more difficult for the non-specialist to identify his species of fossils. At the same time, with the growing refinements in stratigraphy, it is ever becoming more important to the stratigraphic

geologist to give close attention to the fossil faunas present in his rock formations, and to have accurate identifications of his fossils. It is, therefore, a pleasure to notice the appearance of such a work as *North American Index Fossils* by Grabau and Shimer.

In the two volumes of 853 and 909 pages respectively which comprise this work, approximately 1,500 genera and 4,000 species are defined, a large portion of the species being accompanied by illustrations incorporated in the text, the figures being copied from various sources for which credit is always given. The species selected for definition have been chosen to include, first, those most characteristic of important stratigraphic divisions, i.e., those of wide geographic and limited stratigraphic range; secondly, those having a wide geographic distribution even though their stratigraphic range is also great, i.e., the very common American species; and thirdly, forms which it is important that students of structural and anatomical paleontology should understand. The species are arranged chronologically under their respective genera, the genera being arranged systematically under their proper families, orders, classes, and phyla. Brief discussions of the structural features of each phylum and class are included, but except in the case of the Arthropoda, no definitions of subclasses or orders are given. Under each class is given a brief bibliography of the more important literature, which will be of use to such as wish to carry their studies beyond the limits of the work. A decided innovation is the inclusion of extensive analytical keys to the genera under each of the classes. These keys are probably the most elaborate ever attempted for fossil invertebrates, and will doubtless be of much value to those using the books, although it must be kept in mind always that such keys can never be of so great utility in the classification of fossils, which are frequently if not usually represented by more or less incomplete specimens, as in the classification of living organisms.

The closing pages of the second volume are given up to a series of appendices, as follows: A, Summary of North American Stratigraphy, Tables of Geological Formations (50 pages); B, Faunal Summary, Tables Showing Distribution of Species Described (50 pages); C, General Bibliography of North American Invertebrate Index Fossils and Fossil Faunas (1832–1909) (89 pages). In this bibliography the titles are arranged in accordance with the geological systems, those for each system being grouped geographically; D, Hints for Collecting and Preparing Fossil Invertebrates (16 pages); E, Glossary (36 pages) and General Index.

These volumes have been prepared primarily for the non-specialist, more especially for workers in stratigraphic geology who have not received special training in paleontology. For such workers, as well as for geological students in colleges and universities, and for amateur paleontologists and collectors of fossils, the volumes will prove to be of great value.

S. W.

Olenellus and Other Genera of the Mesonacidae. By CHARLES D. WALCOTT, Smithsonian Miscellaneous Collections, LV, No. 6.

In his memoir on the *Olenellus* fauna, published in the *Tenth Annual Report of the United States Geological Survey*, in 1891, Walcott recognized seven American and three foreign species of *Olenellus*, included in three subgeneric groups, *Olenellus* proper, *Mesonacis*, and *Holmia*. The present contribution represents the advance of knowledge concerning this highly interesting group of Cambrian trilobites since the appearance of the earlier memoir. Thirty-four species, including two varieties, are now recognized, besides two undetermined ones, thirty-six in all, arranged in ten groups which are given full generic rank, the entire group of forms being elevated to a family under the name *Mesonacidae*. Twenty-four of these forms are American and twelve foreign, the foreign representatives being known only from northwestern Europe.

With the restriction of the genus *Olenellus* to include only one group of these species, it comes about that this genus is no longer characteristic of the entire Lower Cambrian, as has commonly been assumed since the publication of the earlier memoir, but occurs only in the uppermost division of the series. In the present paper the Lower Cambrian is divided into four faunal zones, designated, beginning with the oldest, (1) *Nevadia* zone, (2) *Elliptocephala* zone, (3) *Callavia* zone, (4) *Olenellus* zone, each named from the leading Mesonacid genus present in the fauna. Aside from these four index genera the following are recognized: *Mesonacis* Walcott, *Holmia* Matthew, *Wanneria* n. gen., *Paedeumias* n. gen., *Peachella* n. gen., and *Olenelloides* Peach.

In their genetic relations the genera discussed are assumed to diverge along two lines from the primitive *Nevadia*. The one line includes *Callavia*, *Holmia*, and *Wanneria* in order, the last of which is supposed to give origin to *Paradoxides* of the Middle Cambrian. The second line of descent springing from *Nevadia* includes *Mesonacis*, *Elliptocephala*, *Paedeumias*, and *Olenellus* in serial order, the last of these genera giving origin on the one hand to *Peachella* and on the other hand to *Olenelloides*.

Some question may be raised, perhaps, as to the legitimacy of the assumption of such a phylogenetic origin of *Paradoxides*. The most diagnostic character of the entire family *Mesonacidae* is the absence of a facial suture, although well-developed compound eyes are present. Elsewhere among the trilobites, where the free and fixed cheeks have become anchylosed, with the consequent disappearance of the facial suture, as, for instance, in the Devonian genus *Phacops*, this character has appeared at the termination of a long phylogenetic line in which all the earlier members possess functional facial sutures. The facial suture is so characteristic of every order and every family of trilobites, save the *Mesonacidae*, that one is forced to the assumption that it was a character of the primitive stock from which all have sprung. It therefore seems necessary to assume that the ancestors of the *Mesonacidae* possessed a functional facial suture, and that the absence of this character in this group of genera is indicative of its terminal position in a long phylogenetic line whose pre-Cambrian history is unknown to us. Since such a character when once lost cannot be restored again, it would follow that *Paradoxides* with its functional facial suture could not have originated from any member of the *Mesonacidae*. Might it not be assumed that *Paradoxides* arose from a totally distinct phylogenetic line in a different early Cambrian biologic province, perhaps southern Europe, and later migrated into the North Atlantic province where it occurs in strata generally younger than those bearing the Mesonacid faunas? Under such an interpretation it would be necessary to grant that somewhere *Paradoxides* may have been contemporaneous with at least a portion of the Mesonacid faunas in North America, and this contemporaneity may even have extended to the North American shore of the North Atlantic basin.

The paper adds much to our knowledge of these very ancient faunas of the earth, and the author is to be congratulated upon the success of his most persistent search for these rare fossil forms. Not the least attractive portion of the paper are the twenty-two beautifully executed half-tone plates.

S. W.

Elements of Geology. By ELIOT BLACKWELDER AND HARLAN H. BARROWS. Pp. 475; figs. 485; pls. 16. New York: American Book Co., 1911.

This is not a manual or reference book, but an elementary textbook intended primarily for use by young students in the high schools, acade-

mies, and institutions of similar grade. The book was written in the belief that it is the function of a text as well as the duty of a teacher to develop in the student the power to reason. This spirit pervades the work throughout.

The method is essentially analytical and the text explanatory rather than descriptive. Abundant use is made of questions which are ingeniously devised to guide the student's mental operations and to lead him unconsciously through certain desired chains of reasoning. Many of the questions are inserted in the text—a practice which makes the student stop and think and, by causing him to tie his ideas together, incidentally and unconsciously brings him to see the interrelation of the different geologic agents and processes.

The treatment throughout indicates a continuous desire to prevent the student from forming hard-and-fast conceptions of processes and geologic features that are necessarily often variable. There is a steady determination to compel the student to maintain a critical open mind and at the same time to draw close distinctions in the use of variable terms, as in the relative heights of hills and mountains and of plains and plateaus. Sometimes, however, this most laudable endeavor threatens to overstep itself and lumber up the text with hypercritical qualifications. In an elementary textbook where space is severely limited unessential discriminations crowd out more weighty matter, while the student on his part may come to give too much thought to precision in little things at the expense of a grasp of great things. But this is only another item in the ever-present question of where to draw the line.

The text is clear, direct, and well written. In some cases, as in chap. i, the opening paragraph is a bit wobbly, but when the initial groping for just the right line is past and the topic is well under way, the chain of ideas, like the language, flows evenly and gracefully along without effort.

Poise and balance characterize the treatment of facts and principles. The essential features are treated clearly though concisely, and the minor features are subordinated or left out where their omission does not weaken the presentation of the main topics. Unessential facts have been carefully pruned. Keen discrimination is apparent here.

The departure of the authors from current practice in the arrangement of material will be most conspicuously seen in the omission of separate chapters on vulcanism and earthquakes. This was done in the belief that volcanoes and especially earthquakes are exceptional

and local phenomena and that although spectacular and ever interesting to the popular mind, they are not entitled to the same space in such a work as are the more general geologic processes. The main features of vulcanism and volcanic rocks are, however, quite adequately treated in the chapter on the composition of the earth, while volcanic mountains as surface features appear in the very excellent chapter entitled "The Great Relief Features of the Land."

The proper handling of historical geology in brief space is a difficult task. There is a great deal of ground to be covered and a great mass of material to be judiciously picked over. Unless the work is well done, the residue left is apt to be a dry bone skeleton with the flesh and blood largely gone. In the historical portion of this work the salient and vital points are made to stand out clearly. This is particularly true of the life history. In part this is secured by a sprightly use of paragraph headings to feature the various vicissitudes through which life forms have passed in their long history. With these in mind, the significance of the discussion is more readily grasped and the details are more easily retained.

The authors have treated the Tertiary as a "Period," giving it the same rank in the geologic time scale as they do the Comanche or the Cretaceous. After stating that it is divided into the Eocene, Miocene, and Pliocene epochs, the Tertiary is discussed largely as a unit. The Tertiary presents many rich problems for advanced students, especially its mammalian evolution and its diastrophism, but these are perhaps beyond the reach of a beginning class. The authors, believing that the points of newness or striking facts are largely over by the time the Tertiary is reached, have apparently thought it best to curtail the treatment and advance rapidly to the close of the history.

A feature which cannot be too highly commended is the extensive use of three-dimension diagrams to portray the operation of geologic processes. This, in the reviewer's opinion, is much more expressive than the ordinary style. The set of three block diagrams on p. 146 which picture the successive development of youthful, mature, and old topography, illustrating not only the surface development of the streams but the simultaneous lowering of the land toward peneplanation, shows the possibilities of the method.

By reducing the size of the illustrations, a very large number have been successfully introduced and add very greatly to the effectiveness and attractiveness of the book. It is a veritable picture book with most of the pictures new to geologic readers.

Finally it may be said that the general scheme and mode of treatment of the book follow the lead of the comprehensive treatise of Chamberlin and Salisbury, and the fundamental views which give distinctive character to that work find reflection in this.

R. T. C.

Geology of the Kiruna District (2). Igneous Rocks and Iron Ore of Kürunavaara Luossovaara and Tualluvaara. Academical Dissertation by PER A. GEIJER, for the degree of Doctor of Philosophy. By the permission of the philosophical faculty of the University of Upsala. Stockholm. 1910. Pp. 278; 2 geologic maps.

The district is in northern Lapland. The rocks, which are generally regarded as pre-Cambrian, include greenstones, conglomerates, syenite porphyries, magnetite ores, quartz porphyry, phyllites, sandstones, etc. They are strongly folded and in general stand nearly vertical but otherwise do not show pronounced metamorphism. The textures are well preserved. A typical ore body is the one of Kürunavaara which forms the backbone of a mountain about 748 meters high. This ore body is over 5 kilometers long and some 96 meters wide. Other ore bodies are somewhat smaller. The ore zone is included between quartz porphyry and syenite porphyry. The minerals of the ore are magnetite, hematite (subordinate), fluor-apatite, augite, amphibole, biotite, titanite, tourmaline, zircon, etc. Generally there is enough apatite to place the ore above the Bessemer limit.

The ore minerals are intergrown like those of an igneous rock and contacts between ore and country rock are in places gradational. All of the minerals of the ore except tourmaline are primary constituents of igneous rocks near by. Rock textures indicate that the ore mass has crystallized quite in the same way as an igneous rock—these include trachytoidal flow structure, skeleton forms of magnetite, and the ophitic distribution of augite. The ores are believed to be of magmatic origin and the writer is inclined to the view that the associated syenites are effusive in character. He does not agree with De Launey, who held that the ores were deposited at the surface from gases and hot solutions by pneumatolytic-sedimentary processes. The writer does not feel sure as to the nature of the differentiation processes which have resulted in the product, but does believe that such an origin is proven.

W. H. E.

The Edmonton Coal Field, Alberta. By D. B. DOWLING. Canada Department of Mines, Geological Survey Branch, 1910. 59 pages, 2 maps.

The area primarily considered is on the Saskatchewan River, in and near Edmonton, but a short discussion of the surrounding coal fields is included. The coal is lignitic or semi-bituminous, and occurs near the middle and at the top of 700 feet of brackish water deposits, the Edmonton formation, at the top of the Cretaceous, and in Tertiary sandstone above. The lower horizon, the Clover Bar seam, is worked at Edmonton, and 80,000,000 tons are estimated to be available in an area of 14 square miles.

W. A. T.

Preliminary Memoir on the Lewes and Nordenskiold Rivers Coal District, Yukon Territory. By D. D. CAIRNES. Canada Department of Mines, Geological Survey Branch, 1910. 70 pages, 2 maps.

The development of the Whitehorse copper deposits was the incentive for the investigation of the available coal resources in the district described in this report. The important formations of the district are the Braeburn limestone (carboniferous?), the Laberge series, conglomerates, shales, sandstones, etc., and Tantalus conglomerates, Jurasso-Cretaceous. Tertiary volcanics have broken through these formations and overflowed them in many places. Important coking coal seams occur in the Tantalus conglomerates and near the top of the Laberge series, but they are available only near the navigable water, such as the Lewes River and Lake Laberge.

W. A. T.

Geology of the Nipigon Basin, Ontario. By A. W. G. WILSON. Canada Department of Mines, Geological Survey Branch, 1910. 152 pages, 1 map.

The region covered by this excellent report is underlain mainly by Laurentian gneisses and granites, but scattered over it are areas of greenstones and green schists, called Keewatin. A few bands of Lower Huronian rocks are known. Lying on the eroded surface of these formations is a series of conglomerates, sandstones, shales, and dolomitic limestones classed as Keweenawan, although the author believes

they might be younger than pre-Cambrian. The youngest rock is a diabase, which occurs as intrusive sheets and flows. The evidence for and against the diabase occurring as a volcanic flow is fully discussed, the conclusion being that as now known they are basal residuals of former extensive flows.

The glacial geology is briefly discussed, the author concluding that ice erosion was very limited, except locally. The physiographic features are considered, also the economic geology, but no deposits of any value are known.

W. A. T.

The Geology and Ore Deposits of the West Pilbara Goldfield. By H. P. WOODWARD. Bull. No. 41, Western Australia Geological Survey. Pp. 142; 5 geological maps; 1 mining plan; 25 figs.

The first part of the bulletin is devoted to a general discussion of the physiography, geology, and petrography of the district, which occupies the triangular portion of the northwest division of the state included between the Fortescue and Yule rivers. The southern part of the area is a high tableland which drops abruptly to the wide, low coastal plain forming the northern part.

The oldest rocks in the region are metamorphosed sedimentaries—clay slates and shales—that have been intruded successively by dolerite, gabbro, and granite. The last is thought to have altered some of the clay slates and dolerites to crystalline schists. A period of subsidence was accompanied by an outburst of volcanic activity in the form of fissure eruptions of very fluid basic lava. Subsidence continued, and marine beds are found above the last lava flow. Re-elevation and denudation have given rise to the present topography. The various formations are described in some detail, and petrological notes on seventy specimens are appended.

The second part of the bulletin is devoted to a more detailed description of the country and the mining centers visited. The lodes are most frequently found in the altered sedimentaries. They carry, in addition to gold, varying amounts of pyrite, chalcopyrite, and galena. Little evidence regarding the genesis of the lodes is presented. Much of the material is of greater interest to the engineer and the investor than to the geologist.

A. D. B.

A Review of Mining Operations in the State of South Australia during the Half-Year Ended December 31, 1910. No. 13. Issued by T. DUFFIELD, Secretary for Mines. Adelaide, 1911. Pp. 34; pls. 2.

This paper gives statistics on leases, claims, subsidies, men employed, prices, and various industrial and technical features of the mining districts of South Australia. Notes on recent development work, including assays of samples and amount of boring, tunneling, etc., done on various properties make up a large part of the review.

An interesting method of draining the southeastern district has been approved by the government geologist. The plan is to sink borings or shafts into a porous stratum underlying the swamp areas and allow the water to escape through underground channels, saving the expense of extensive ditches necessary for surface drainage. Small areas have been drained into natural sink holes with very encouraging results.

A. D. B.

Report on the Iron Ore Deposits along the Ottawa (Quebec Side) and Gatineau Rivers. By FRITZ CIRKEL. Canada Department of Mines, Mines Branch. No. 23, 1909. Pp. 147; plates 5; maps 2.

The area covered by this report is about 900 square miles, extending from Ottawa 100 miles up the Ottawa River and 83 miles up the Gatineau. Deposits of magnetite and hematite ore have been known for over sixty years and attempts have been made at various times to develop them, but without success. The present report is the result of a comprehensive examination of the region to determine the possibilities of development of the deposits. One important factor is the available water power which is described in detail in the appendix.

E. R. L.

Maryland Geological Survey, Vol. VIII, 1909. WILLIAM BULLOCK CLARK, State Geologist.

This volume, which is entirely economic in its nature, contains the following reports: Part I, "Second Report on State Highway Construction," by Walter Wilson Crosby, pp. 29–95; Part II, "Maryland Mineral Industries, 1896–1907," by Wm. Bullock Clark and Edward B. Mathews, pp. 99–223; Part III, "Report on the Limestones of Maryland with Special Reference to their Use in the Manufacture of Lime

and Cement," by Edward Bennett Mathews and John Sharshall Grasty, pp. 225–477.

E. R. L.

Missouri Bureau of Geology and Mines. Biennial Report of the State Geologist for the Years 1909 and 1910. By H. A. BUEHLER AND OTHERS.

The report contains a summary of the present and proposed work of the bureau and the following chapters descriptive of work now in progress: "The Principal Coal Fields of Northern Missouri," by Henry Hinds, pp. 26–35; "Reconnaissance Work," by V. H. Hughes, pp. 36–54; and "The Geology of the Newburg Area," by Wallace Lee, pp. 55–63.

E. R. L.

Mississippi State Geological Survey, 1907. ALBERT F. CRIDER, Director.

The volume contains the following reports: Bulletin No. I, "Cement and Portland Cement Materials of Mississippi," by Albert F. Crider, pp. 73; Bulletin No. II, "Clays of Mississippi, Part 1, Brick Clays and Clay Industry of Northern Mississippi," by William N. Logan, pp. 255; Bulletin No. III, "The Lignite of Mississippi," by Calvin S. Brown, pp. 71.

E. R. L.

The Geology of the Whatatutu Subdivision, Raukumara Division, Poverty Bay. By JAMES HENRY ADAMS. New Zealand Geological Survey, Bulletin No. 9 (New Series). Wellington, 1910. Pp. 48; maps 5; plates 3.

The Raukumara division lies on the eastern side of the North Island of New Zealand and consists of a series of rolling ridges of moderate height separated by deeply cut river valleys. The rocks belong chiefly to the Whatatutu series which are upper Miocene in age and which are folded into irregular anticlines and synclines. Indications of oil have been found at various points within the region and the object of the survey was to obtain information as to the possibilities of development. With this end in view the anticlines and synclines were mapped and described with considerable care. Fossils are abundant in some localities but have received little attention in this report.

E. R. L.